IRRIGATION PRACTICE AND ENGINEERING

VOLUME I

USE OF IRRIGATION WATER

AND

IRRIGATION PRACTICE

IRRIGATION PRACTICE AND ENGINEERING

THREE VOLUMES

BY

B. A. ETCHEVERRY
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VOL. I —USE OF IRRIGATION WATER AND IRRIGATION PRACTICE
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ENGINEERING

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PREFACE

In the preparation of this volume and of the two following larger volumes, the author has endeavored to present a book which will fill the needs of teachers and students in technical colleges and universities and which may be used as a reference book by engineers engaged in irrigation work, by managers and superintendents of irrigation systems. In this work the writer has been guided by his experience as a teacher of irrigation practice and engineering for many years and by experience obtained through his professional practice, which has given him opportunities to become acquainted with irrigation practice and projects in most of the states of the western part of the United States and in western Canada.

Personal contact with engineers engaged in irrigation work, examination of their reports and plans for proposed irrigation systems and inspection of constructed systems show that engineers who have had little experience in irrigation work have not considered the relative importance of the agricultural phase of irrigation problems. The planning and construction of an irrigation system cannot be totally separated from the operation of the system. On nearly all new projects the completion of the construction of a system and the operation of the system must be carried on at the same time, usually both under the direction of the chief engineer. Where an old system is to be extended, construction and operation must be carried jointly. It usually develops that the experience obtained by the engineer in planning and constructing a system makes him the best qualified man to operate the system, and not infrequently does he become the manager of the project. For these reasons it is important that a treatise on irrigation engineering be preceded by an introductory part on the use of irrigation water and irrigation practice.

In this volume the author has confined himself largely to irrigation practice in the United States, and has carefully selected the principles and information obtainable from the best available literature. In the table of references at the end of each chapter is given a partial list of the most important publications which have been consulted and to which the reader is referred for more detailed information.

Chapters I and II deal with the relation of soil moisture to plant growth and the disposal of irrigation water applied to the soil. They are of value in their bearing on the methods of application of water to the land, to maintain the proper moisture condition of the soil and prevent waste of irrigation water. The importance of a knowledge of these subjects is apparent when the best available data shows that probably from 50 to 60 per cent. of the water delivered to farms is lost by deep percolation beyond the reach of plant roots, by evaporation and by surface waste. Various estimates made by reliable authorities indicate that from 15 to 25 per cent. of all irrigated lands are damaged by water-logging or rise of alkali produced by wasteful methods of irrigation and by the loss of water from irrigation canals.

Chapters III and IV present the best available information and results, obtained by investigations, experiments, and measurements, on the quantity of irrigation water and the time of application to give the most economic use of water in the production of crops.

Chapter V on the duty of water defines the units of measurement of irrigation water and presents the water consumption in typical irrigated districts and on several projects in each of the arid states. The ratio between gross duty and net duty, which expresses the loss of water in conveyance from the point of diversion at the head of the canal system to the point of delivery to the farm, is given for a large number of projects. The importance of this data in the design of canal systems is apparent when the results show that on most projects from 30 to 60 per cent. of the water diverted is lost between the point of diversion and the point of delivery.

The seasonal duty, which gives the variations in water demand and consumption during the different months of the irrigation season, has been worked out for a large number of projects and should be considered in the planning of the carrying capacities of the canals of an irrigation system.

Chapter VI describes the methods of preparing land for irrigation and the methods of applying water to the land. A knowledge of these subjects is necessary to obtain the economic use of water and is important in the design of the distribution system and in the operation of the project.

In Chapter VII on farm ditches and structures the author has attempted to confine himself to ditches and structures used for

the conveyance and distribution of water on the farm as different from those pertaining to the distribution system of the project which conveys and delivers the water to each farm. Large farms and certain methods of applying water to the land, for which large streams of water must be used, may require ditches and structures of such sizes that there will be little or no difference between them and those used for the laterals of irrigation projects. In this chapter technical principles of design have not been considered, as these are fully discussed in the part of the book dealing with Irrigation Engineering.

Chapter VIII deals with small pumping plants and is limited to a consideration of the types of installations, the conditions for which each type is best adapted, the cost of installation and the annual cost of operation and maintenance. The individual small pumping plant is a common means of development of water for irrigation and for this reason has been considered in a non-technical manner in this volume.

The main part of the book, to which this volume is introductory, considers in greater detail than has heretofore been done in books on irrigation engineering the principles of design of canals, and structures pertaining to an irrigation system. To make the book of greater value as a reference book for practising engineers, each type of structure is illustrated by well-selected examples, accompanied in many cases by cost data, and methods of construction of special value in irrigation work are described.

In presenting this volume, the author wishes to acknowledge his indebtedness to the large number of publications from which much valuable information has been obtained. Special acknowledgment is made of the valuable bulletins of the U. S. Department of Agriculture and of the various reports and publications of the U. S. Reclamation Service; the author has drawn freely from these sources and believes that by so doing much has been added to the value of the book.

The tabulated references presented at the end of each chapter and the indicated source of certain illustrations will serve as specific acknowledgment.

B. A. Etcheverry.

Berkeley, California,
June, 1914.

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CHAPTER I

SOIL MOISTURE AND PLANT GROWTH, AND THEIR BEARING ON IRRIGATION PRACTICE

The intelligent use of water in irrigation requires a correct understanding of the conditions in which water exists in the soil and of the forces controlling its distribution

Soil water occurs in the following forms:

(1) Hygroscopic water,
(2) Capillary water,
(3) Gravity water.

Hygroscopic water is that which occurs in all soils not dried by artificial heating. It is the moisture which a soil dried by artificial heat will absorb from moist air. It exists as a very thin film surrounding each particle, but is distinguished from capillary water in that it does not move by capillary action or otherwise; it cannot be readily removed by evaporation by exposure to air, and cannot be absorbed by the plant roots in sufficient quantities to be of any practical value to sustain plant growth. The amount of hygroscopic moisture increases with the surface exposed to the air, or fineness of particles, with the amount of humus in the soil, and when in saturated air with an increase in temperature. The table on page 2 presents average values for the quantity of hygroscopic moisture in soils of different arid states as given by Prof. Hilgard. The determinations are for a saturated atmosphere at 15° Centigrade.

Prof. Loughridge has obtained, from a large number of soil moisture determinations of California soils the following general

AVERAGE HYGROSCOPIC MOISTURE IN ARID REGION OF UNITED STATES, BY HILGARD

	Number analyzed	Hygroscopic moisture in per cent. of soil weight		Number analyzed	Hygroscopic moisture in per cent. of soil weight
Montana....	59	7.14	Utah........	38	2.37
Idaho.......	17	2.00	California....	262	6.09
Colorado....	16	2.31	Washington (East of Cascades)	109	5.14

values for the quantity of hygroscopic water in different types of soil:

Sandy soils...........................	1– 3 per cent.
Sandy loam soils......................	3– 5 per cent.
Loam soils............................	5 per cent.
Clay loams............................	5– 7 per cent.
Clay soils............................	7–10 per cent.

That hygroscopic moisture is of no practical value to produce plant growth is shown by the results obtained by Lyman J. Briggs, which are based on extensive experiments in which all precautions were taken for accurate determinations. Different plants were grown in different soils placed in glass pots, and the soil surface was covered with a wax seal to prevent soil moisture evaporation which would tend to destroy the uniform distribution of moisture in the soil. The results of a large number of determinations are given in the table on page 3.

The hygroscopic coefficient is the per cent. of moisture, based on the dry weight of the soil, that a dry soil will absorb when placed in a saturated atmosphere.

The wilting coefficient is the per cent. of moisture, based on the dry weight of the soil, which remains in the soil at the time when the plants have reached a condition of permanent wilting.

The mean ratio of the hygroscopic coefficient to the wilting coefficient, obtained from these determinations, is 0.68. The determinations made by Heinrich give a ratio of 0.696; a single determination made by F. J. Alway gave a ratio of 0.65. These results show that the wilting coefficient is greater than the hygroscopic coefficient and is about equal to 1.50 times the hygroscopic coefficient.

Capillary water exists as a thickened film of water around each soil particle and partially fills the pore spaces. It is held in the

RELATION OF WILTING COEFFICIENT TO HYGROSCOPIC MOISTURE

Types of soils	Hygroscopic coefficient	Wilting coefficient	Ratio
Coarse sand	0.5	0.9	0.556
Fine sand	1.5	2.6	0.577
Fine sand	2.3	3.3	0.698
Fine sand	2.3	3.6	0.639
Sandy loam	3.5	4.8	0.729
Sandy loam	4.4	6.3	0.699
Sandy loam	6.3	9.9	0.636
Fine sandy loam	6.5	9.7	0.670
Fine sandy loam	6.6	10.8	0.611
Fine sandy loam	7.5	11.6	0.646
Loam	7.8	10.3	0.757
Loam	9.8	13.9	0.705
Loam	9.6	15.2	0.631
Clay loam	11.8	14.6	0.808
Clay loam	13.2	16.2	0.815
Clay loam	11.2	16.5	0.679
Clay loam	11.4	16.3	0.700
Mean	....	....	0.680

soil against gravity by the attraction between soil and water and by the cohesion between water molecules, and is not drawn out by drainage. It moves in the soil in any direction, and rises in the channels formed by the pores between soil particles because of the same action which draws the oil up a lamp wick. Capillary water is of greatest importance to plant growth. It covers the roots and the small diminutive root-hairs, which absorb it by the osmotic pressure. From the roots the water, with the mineral salts or plant food which it contains in solution, rises into the stems up to the leaves, and by the process of plant transpiration it passes into the air, leaving behind the plant food which in combination with the carbonic acid absorbed from the air, forms the plant.

Capillary water moves from a wet soil to a drier soil; this is what causes it to spread laterally and to rise from the wetter subsoil to the surface, from where it passes into the air by evaporation. The water will rise to a greater height in a fine textured soil than in a coarse textured soil, but will rise more quickly in the coarse textured soil. Professor Hilgard found that the maximum height to which water rose was 17 inches in 6 days for a sandy soil, and 46 inches in 195 days for a clay soil.

In the sandy soil it took 1 hour to rise 8 inches, while in the clay soil it took 12 hours to rise to the same height. Lyon and Fippin give the following values for extent and rate of capillarity;

CAPILLARY RISE IN INCHES FOR DIFFERENT LENGTHS OF TIME

Kind of soil	Time							
	½hr.	1 hr.	2 hrs.	1 day	3 days	8 days	13 days	19 days
Silt and very fine sand	2.7	4.7	7.0	20.0	30.0	45.0	52.0	56.0
Very fine sand	7.6	10.0	12.4	21.0	23.0	26.0	27.5	28.5
Fine sand	9.0	9.5	10.0	11.6	13.0	14.3	15.2	16.0
Coarse and medium sand	5.8	6.0	6.3	7.5	9.0	10.0	11.5	12.5
Fine gravel	4.0	5.0	5.3	6.4	8.0	9.0	10.0	10.8

The quantity of capillary water which may be held by the soil will depend not only on the kind of soil but on the extent to which it is drained or the distance through which the capillary action takes place. Under field conditions the soil next to the water-table will be saturated and the moisture content will decrease above this point in proportion to the distance from the water-table. Where the water-table is far from the surface, which is the usual condition of arid soils, at least before the waterlogging produced by excessive irrigation and lack of natural drainage, the capillary water, supplied by irrigation, is disseminated through the soil and held against gravity. The capacity of a soil in this condition to hold water has been called by Dr. Widtsoe the field capacity of soil for capillary water, but includes also hygroscopic water. Dr. Widtsoe gives the following values for the field capacity of different soils for capillary water, including hygroscopic water, expressed in per cent. by weight and based on several thousand trials:

Field capacity of different soils for soil moisture

For a clay soil to a depth of 8 feet, 19 per cent. by weight.
For a clay loam to a depth of 8 feet, 18 per cent. by weight.
For a loam to a depth of 8 feet, 16–17 per cent. by weight.
For a sandy loam to a depth of 8 feet, 14 1/2 per cent. by weight.
For a very sandy loam, depth of 8 feet, 14 per cent. by weight.

Gravity water is that water which moves downward through the soil pores because of gravity. When the soil is saturated the pores are entirely filled with water, and that water which fills the space in parts not occupied by capillary water is gravity water. Gravity water is not retained by the soil if there is

natural or artificial drainage. It passes downward, supplying capillary water to the soil below, and the excess reaches the water table or a drainage channel. When there is an excess of gravity water, it passes down to a depth which is too far below the lower end of plant roots to be drawn up by capillarity and is wasted.

A soil which is saturated contains gravity, capillary and hygroscopic moisture. A soil which is air dried in the sun contains hygroscopic moisture only, and a soil which is dried by artificial heat contains no moisture.

METHODS OF MAKING SOIL MOISTURE DETERMINATIONS

The soil samples usually taken with augers are immediately placed in a fruit jar, or other air-tight jar, to prevent any loss by evaporation. The percentage of moisture is determined by weighing out on a tin or preferably a glass plate 100 grams (or any other convenient weight) of the well mixed soil, before losing any moisture; then spread the weighed sample on the plate and dry it. The loss in weight in ounces will then be the per cent. of water by weight in the moist soil. A more accurate form of expression is to state the per cent. of moisture on a dry soil basis. The per cent. of moisture is then equal to the loss in weight, multiplied by 100 and divided by the dry weight. The method of drying will affect the results. The method most generally used is to dry the soil for several hours at a temperature of about 110° Centigrade; the moisture thus obtained gives total moisture which includes hygroscopic moisture. The method generally used by Hilgard and Loughridge is to expose the soil sample to the sun or until thoroughly air-dried; this gives the per cent. of free moisture and excludes hygroscopic moisture; it more nearly represents the water available to plants.

OPTIMUM PERCENTAGE OF FREE MOISTURE IN SOIL FOR PLANT GROWTH

The pores of most cultivated soils will average from 30 to 60 per cent. of the entire volume; it is smallest for sandy soils and greatest for clay soils. For plants to grow, it is necessary that they have air as well as water, and for best growing condition the water in the soil should range from 40 to 60 per cent. of the pore space. This leaves about an equal space for air. Applying these figures to average soils, the maximum growing condition

will be obtained for a very sandy soil with 30 per cent. pore space when it contains 12 to 18 per cent. by volume of total moisture, and for a heavy clay soil with 50 per cent. pore space when it contains 20 to 30 per cent. by volume of total moisture. Expressed in per cent. by weight, the moisture content should be for a very sandy soil, air dried, weighing 110 pounds per cubic foot, from 6.8 to 10.2 per cent.; for a stiff clay soil weighing 75 pounds per cubic foot, 16.6 to 25 per cent.; and for an average sandy loam, 10 to 15 per cent. The values given by Dr. Widtsoe for the field capacity of soils for water are in general not much greater than those of the desirable amount of water for best growing condition; this indicates that the water retained by a well drained soil, after the application of irrigation water, cannot be much in excess of the optimum moisture content for plant growth.

The effect of excess of moisture in the soil is illustrated in the case of an orchard in sandy soil, where the moisture content in the upper 3 feet as found by Dr. Loughridge averaged 8.5 per cent. and in the fourth foot 15.3 per cent. by weight. The proper moisture content for this soil was about 10 per cent. The excess moisture did not leave sufficient space for the air, which caused the trees to suffer.

MINIMUM AMOUNT OF FREE MOISTURE FOR PLANT GROWTH

The minimum amount of free soil moisture, in excess of the hygroscopic moisture, in the upper 4 feet of soil necessary to keep trees and plants in good growing condition, as obtained by Dr. Loughridge and based on a large number of soil moisture determinations made in California, are given in the following table:

Minimum of Free Moisture for Plant Growth in Upper 4 Feet of Soil, by Dr. Loughridge

Crops	Free moisture in the soil	
	Per cent. by weight	Tons per acre in 4 feet of soil
Apricots, Olives, Peaches, Soya Bean	1.0	80
Citrus, Figs	1.5	120
Almonds, Prunes, Saltbush	2.0	160
Walnuts, Grapes, Eucalyptus	2.5	200
Apples, Prunes	4.0	322
Wheat, corn	5.0	400
Sugar Beets, Sorghum	6.0	480

At the University Farm, Davis, California, measurements made by the Irrigation Investigations showed that the growth of alfalfa was checked when the amount of free moisture was less than 5 to 7 per cent. These results represent field conditions; they are necessarily not accurate, for they are affected by a number of factors which modify them. They represent the minimum free soil moisture content of the upper 4 feet of soil and not of the soil zone which contains the root system. Shallow rooted plants may confine their root system to a smaller depth than the upper 4 feet of soil, and as the surface soil is usually drier than the lower soil, the average moisture content for the 4 feet will be greater than that of the upper part. On the other hand, deep rooted plants, such as fruit trees, may extend their root system far below the 4-foot depth, and the moisture content of the upper 4 feet will be less than that of the greater depth containing the root system. The difference in minimum soil moisture content for different crops is no doubt largely due to these and other factors, which cannot be accurately controlled in field determination. Lyman J. Briggs has carried on by careful laboratory methods extensive experiments on the wilting coefficient of a large variety of plants, grown in different types of soils. The results of about 1,300 determinations show that the soil moisture content at which permanent wilting first takes place varies very little with the kind of plant; and for the different types of soil the wilting coefficient is equal to about 1.50 times the hygroscopic coefficient. From this conclusion the minimum free soil moisture in excess of the hygroscopic moisture at the wilting point is equal to one-half the hygroscopic coefficient; this relation applied to the different types of soil and their corresponding hygroscopic coefficient, as given by Prof. Loughridge for California soils (see page 2), gives the following values for minimum free soil moistures:

Sandy soils	0.5–1.5 per cent. by weight
Sandy loam soils	1.5–2.5 per cent. by weight
Loam soils	2.5 per cent. by weight
Clay loams	2.5–3.5 per cent. by weight
Clay soils	3.5–5.0 per cent. by weight

SOIL MOISTURE BEFORE AND AFTER IRRIGATION

The moisture content of the soil must never be lowered to the wilting coefficient. Irrigation water should be applied at

sufficient frequent intervals to maintain the moisture content near the optimum value. The degree to which this is obtained in practice is illustrated by the following examples.

Dr. Loughridge found for citrus orchards in Southern California, irrigated by deep furrows, that the percentage of free soil moisture (in excess of hygroscopic moisture) for a sandy loam averaged before irrigation about 4.68 per cent. for the upper 4 feet and 5.76 for the upper 13 feet, and immediately after the irrigation the percentage in the upper 4 feet averaged about 9.64 per cent. Six weeks after irrigation, the amount of moisture was a little greater than previous to the application of water. About one-fifth of the water applied remained in the soil; the other four-fifths had been taken up by soil evaporation and plant transpiration. For a clay loam soil, the percentage of moisture averaged, for 5 feet depth of soil, 6.81 before irrigation, 11.27 immediately after irrigation, and 1 month after irrigation the moisture percentage was nearly the same as before the irrigation. On a heavy loam the percentage of free moisture was 5.47 before irrigation and 10.86 immediately after irrigation.

In Bulletin No. 115 of the Utah Agricultural College on The Movement of Water in Irrigated Soils, by J. A. Widtsoe and W. W. McLaughlin, are given some interesting results regarding the total soil moisture remaining in the upper 8 feet of irrigated soils several weeks after irrigation for different crops and also the distribution of soil moisture before and after irrigation. The soil used was a heavy loam, with about 50 per cent. voids, weighing when dry about 76 pounds per cubic foot. The optimum water content of the soil, which requires that the pore space be 40 to 60 per cent. filled with water, would be 16.4 to 24.6 per cent. by weight. The minimum water content or water content at wilting point should, according to Briggs, be 1 1/2 times the hygroscopic coefficient. The hygroscopic coefficient at different depths of the soil and the results of the soil moisture determinations are given in the following tables. The hygroscopic moisture is subtracted from the total moisture content to give the free moisture percentages.

Hygroscopic Moisture, Logan, Utah

Depth of soil in feet.	2	3	7	8	Average
Per cent. of water on dry basis.	5.02	4.80	4.89	3.61	4.33

EXTENT TO WHICH SOILS DRY OUT AFTER IRRIGATION, LOGAN, UTAH

Crops	No. days after irrigation	No. of trials	Per cent. of total moisture (foot sections) in per cent. by weight								Average	Average free moisture
			1	2	3	4	5	6	7	8		
Corn	38	2	8.83	8.87	11.03	9.59	11.27	11.03	8.95	9.47	9.88	5.55
Sugar beets	35	7	6.86	9.54	11.78	12.26	11.61	14.33	11.90	11.76	11.26	6.93
Potatoes	32	5	9.27	10.76	13.63	14.94	13.15	13.54	13.29	11.92	12.44	6.11
Oats	34	3	6.05	7.03	10.15	8.82	11.46	9.22	9.97	12.15	9.36	5.03
Wheat	40	14	5.64	6.52	7.56	8.28	7.19	9.38	10.94	10.15	8.21	3.98
Alfalfa	31	4	8.34	8.08	7.60	6.49	5.78	6.64	.....	.....	6.82	1.92
Peas	27	3	7.66	8.61	9.75	11.32	13.47	13.28	.....	.....	10.68	5.78
Corn	55	4	9.72	10.02	10.27	10.89	10.88	9.23	.....	.....	10.17	5.27
Bare soil (cultivated).	36	3	18.63	18.63	17.91	18.26	.....	.....	.....	.....	18.38	13.48

These determinations show that in all cases, with the exception of the alfalfa crop, the total moisture remaining was well above the wilting coefficient, as determined by Briggs' rule.

DISTRIBUTION OF TOTAL SOIL MOISTURE BEFORE AND AFTER IRRIGATION, LOGAN, UTAH, 1902

(In per cent. of dry soil)

Depth of water applied	No. of trials	Before or after an irrigation	Per cent. of total water (foot sections)								Average	Average free moisture
			1	2	3	4	5	6	7	8		
2.5 in.	23	Before	9.57	10.55	11.78	12.97	11.92	11.41	11.75	11.49	11.43	7.10
		After	19.24	13.70	13.17	13.84	12.66	12.72	12.31	12.70	13.67	9.34
		Increase	9.67	3.15	1.39	0.87	0.74	1.31	0.56	1.21	2.24	2.24
5.0 in.	115	Before	12.97	14.08	15.68	16.09	15.21	15.18	14.77	13.92	14.74	10.41
		After	23.92	20.71	19.27	17.95	16.25	15.79	15.60	14.81	18.04	13.71
		Increase	10.95	6.63	3.59	1.86	1.04	0.61	0.83	0.89	3.30	3.30
7.5 in.	44	Before	10.62	12.44	14.44	15.11	14.20	13.40	13.13	13.27	13.33	9.00
		After	23.83	21.83	20.05	17.40	15.87	14.66	14.21	14.15	17.75	13.42
		Increase	13.21	9.39	5.61	2.29	1.67	1.26	1.08	0.88	4.42	4.42

A study of the average figures in the table, on the basis that 1 per cent. increase in soil moisture is equivalent to 0.145 inches of water per foot depth of soil or 1.165 inches for an 8-foot depth of soil, show that when 7.5 inches depth of water was applied, only 5.15 inches or about 69 per cent. was retained; when 5 inches

depth of water was applied, 3.85 inches or 77 per cent. was retained; and when 2.5 inches depth of water was applied, the increase in soil moisture content was 2.6 inches. With the two heavier applications, the water not retained was disposed of by deep percolation beyond the 8-foot depth and by soil moisture evaporation. With the lighter application, all the water was retained and an additional amount was probably drawn up by capillarity from the deeper soil. When sufficient water was added at one irrigation in this case about 5 inches the moisture content was brought up to about the best quantity for plant growth.

FEEDING ZONE OF PLANT ROOTS

The zone of soil in which it is necessary to control the distribution and proper degree of soil moisture for plant growth is that which contains the feeding space of the plant roots. The depth to which the plant roots extend depends on the plant, the character of the soil and subsoil, and the moisture content. The investigations and observations of Dr. Hilgard, Dr. Loughridge, Dr. Widtsoe, and others show that in well-drained, deep, open soils of the arid region the following depths of root penetration may be reached:

Deciduous trees and vineyards	20 to 24 feet
Alfalfa	up to 50 feet
Cereals, corn	4 to 8 feet
Potatoes and sugar beets	3 to 4 feet
Citrus trees	6 to 8 feet

The practice of irrigation frequently causes the rise of the water-table, and when this occurs the feeding zone of plant roots may become too limited for the plant to continue its growth. Dr. Hilgard states that alfalfa requires at least 5 feet to the water-table, while red clover may be grown with the water-table at a depth of 3 feet. Dr. Loughridge found that almond trees suffered in a sandy soil where the fourth foot of soil was near the saturation point. For deciduous trees a soil depth, free from excessive moisture, of 6 feet is probably necessary; and, because of the excess capillary water obtained in an average soil in the first foot above the water-table, will require a water-table at least 7 feet below the surface.

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CHAPTER II

DISPOSAL OF IRRIGATION WATER APPLIED TO THE SOIL: PLANT TRANSPIRATION, SOIL MOISTURE EVAPORATION, SOIL WATER PERCOLATION, SURFACE WASTE

The irrigation water applied to the soil is disposed of in different ways. Some of the water is lost or wasted before it enters the soil, either by direct evaporation from the water surface exposed to the air or by a surface waste or run-off which may occur at the lower end of fields or furrows when the application of water is not properly done. The remainder, which comprises most of the water, enters the soil, and by the action of gravity and capillarity moves laterally and downward into and through the pores and channels formed by the soil particles, and is used as follows: A part of it comes in contact with the fine root hairs, is absorbed by the plant and used to produce plant growth by the process of plant transpiration; another part is lost by evaporation through the action of capillarity, which draws the water from wetter subsoil to the surface where it is exposed to the air, which absorbs it; a third part percolates downward because of gravity, is retained to the limit of the capacity of the soil for capillary water, and the excess passes down beyond the reach of plant roots to the water-table or to the natural drainage channel.

Briefly stated, the water applied to the soil is used as follows:

First.—Plant transpiration, which is the action through which part of the water fulfills a useful purpose in producing plant growth.

Second.—Soil moisture evaporation, which is the process through which soil water is lost by evaporation.

Third.—Soil percolation, which permits the water not retained by the soil to pass beyond the reach of plant roots.

Fourth.—Surface run-off or waste, which represents a loss due to poor method of irrigation.

The correct use of water will be obtained only when the losses of water by evaporation, percolation, and surface waste are

reduced to a minimum. These losses can be largely controlled by proper methods of cultivation and irrigation. The regulation of the relative proportions of the water used by the processes stated above and the minimizing of the losses require a study of the factors influencing them.

PLANT TRANSPIRATION

Plant growth is dependent on air, sunshine, and water. Water plays a very important part. *First*,—the soil moisture must be so regulated that it will not decrease below the minimum at the wilting point, and it must not exceed a maximum above which there is not sufficient air in the soil. *Second*,—enough moisture must be added to supply the amount passing through the plant by the process of transpiration.

A large number of experiments have been made by different investigators to determine the amount of transpiration or water requirement expressed in pounds of water absorbed by the plant to produce 1 pound of dry matter and the factors which may have an influence on it. The investigations of greatest value have been reviewed and summarized by Lyman J. Briggs and H. L. Shantz in Bulletin 285 of the Bureau of Plant Industry, U. S. Department of Agriculture, on the Water Requirement of Plants. The results indicate that the amount of plant food in the soil is of greatest importance; the addition of fertilizers to poor soils may reduce the water requirement one-half or even two-thirds. The amount of transpiration is greater in dry than in moist air; it increases with an increase in temperature, with an increase in air currents, with the amount of sunlight, being a minimum at night; it probably decreases with an increase in the vigor of the plant. The amount of transpiration per pound of dry matter varies largely with different plants; but even for the same plants the results obtained by the different investigators do not agree, probably because of the many factors involved and the different methods used. The table given on page 14 summarizes the results obtained on some of the most common crops.

These results are based on the dry weight of the entire plant. For the cereals it includes the grain and the straw, for potatoes and sugar beets it includes the tubers and roots with the stalk and leaves.

SUMMARY OF AMOUNT OF PLANT TRANSPIRATION MEASUREMENTS IN POUNDS OF WATER PER POUND OF DRY MATTER

Crop	Lawes, 1850, Rothamsted, England	Wollny, 1886, Munich, Germany	Hellriegel, 1883, Dahme, Germany	King, 1892–95, Madison, Wisconsin	Von Seelhorst, 1896–98 Gottingen, Germany	Widtsoe, 1909, Logan, Utah	Leather, 1910–11, Pusa, India	Briggs & Shantz, 1913, Akron, Colorado
Wheat	235	......	359	......	333	546	554	507
Oats	......	665	401	541	......	......	469	614
Barley	258	774	297	388	365	......	468	539
Rye	......	......	377	......	386	......	......	724
Corn	......	233	......	350	......	386	337	369
Sorghum	......	......	......	......	......	......	437	306
Beans	214	......	......	......	......	......	......	......
Peas	235	416	292	477	......	843	563	800
Clover (sweet)	......	......	......	......	......	......	......	709
Alfalfa	......	......	......	......	......	......	......	1,068
Rape	......	912	337	......	......	......	......	441
Potatoes	......	......	......	423	281	......	......	448
Sugar beets	......	......	......	......	......	497	......	377

The experiments carried on in Colorado by Briggs and Shantz for the Bureau of Plant Industry and those of Widtsoe in Utah for the Utah Experiment Station are of special value in the study of the relation of irrigation to plant growth in the western arid states. The experiments of Briggs and Shantz were made by growing the crops in soils placed in galvanized iron tanks, 16 inches in diameter, 26 inches high. To prevent evaporation of soil moisture, the tanks were covered; in the cover, holes were made through which the plant grew, and the spaces around the stems were sealed with wax. The water was applied below the surface soil through the bottom of a flower pot surrounded with gravel placed in the upper part of the tank under the cover. Some of the results obtained by Briggs and Shantz are given on page 15.

The experiments of the Utah Agricultural College were made in tanks 2 1/2 feet high, 2 feet in diameter. These tanks were not covered and no attempt was made to prevent evaporation of soil moisture. To obtain the quantity of water used by plant transpiration, the loss of evaporation from bare soils was subtracted from the total loss by transpiration and soil evaporation (termed Evapo-transpiration by Widtsoe) of cropped tanks. This gives values for plant transpiration which are too small, because the soil evaporation from a bare soil is greater than that

Summary of Amount of Plant Transpiration Measurements in Pounds of Water per Pound of Dry Matter at Akron Colorado, 1911

Crop	Pounds of water per pounds of	
	Grain	Whole plant
Wheat	1,357	507
Oats	1,680	614
Barley	1,243	539
Corn	2,040	369
Sorghum	1,238	306
Spring rye	2,215	724
Sweet clover	....	709
Alfalfa	....	1068
Canadian field pea	2,218	800
Potatoes (tubers)	994	448
Sugar beets (roots)	629	377

of a soil shaded by the crops. It was found that shading entirely the bare soil decreased the soil evaporation loss by 29 per cent. The results obtained for different crops under different conditions of soil saturation for the years 1902, 1904, 1905, on a fertile loam, are shown by the following average figures:

Plant Transpiration and Evapo-transpiration from Experiments of Utah Agricultural College

Crop	Pounds of water for 1 pound of dry matter	
	Evapo-transpiration	Transpiration
Wheat	1,018	458
Sugar beets	630	510
Corn	675	392
Peas	1,119	740

The effect of cultivation and of fertilizers is shown by the following average figures, obtained for a corn crop:

Effect of Cultivation on Plant Transpiration from Experiments of Utah Agricultural College

Soil	Pounds of water for 1 pound of corn (dry weight)	
	Evapo-transpiration	Transpiration
Sandy loam (cultivated)	423	252
Sandy loam (non-cultivated)	754	603
Clay loam (cultivated)	681	428
Clay loam (non-cultivated)	744	535
Clay soil (cultivated)	1,684	582
Clay soil (non-cultivated)	2,019	753

On a naturally fertile sandy loam the evapo-transpiration amounted to 1,133 pounds per pound of corn; the addition of manure decreased this to 949 pounds, and the addition of 1/10 per cent. sodium nitrate decreased it to 857 pounds. The corresponding transpiration figures were 908, 613, and 565.

Similar tank experiments have been carried on by the Irrigation Investigations at the University Farm, Davis, California. The water was applied to the tanks by means of perforated pipes 12 inches below the surface. This method of irrigation nearly eliminates the evaporation loss of soil moisture, as shown by similar experiments made at Riverside, California, which gave for the soil moisture evaporation in 10 days, for bare soil (not shaded), subirrigated at a depth of 12 inches, 6 per cent. of the water applied or a depth of 0.22 inches. The results obtained, therefore, give very nearly the net plant transpiration. The water consumption or plant transpiration for the first season's growth averaged for four cuttings of alfalfa 1,106 pounds per pound of dry alfalfa; during the second growing season the plant transpiration for the four cuttings were: First cut, 497; second, 759; third, 720; fourth, 862; averaging 709.

To express the water consumption of plants in acre inches per ton of dry matter, the following relations are given:

100 lb. of water for 1 lb. of dry matter is equivalent to 0.885 acre inches per ton of dry matter.
200 lb. of water for 1 lb. of dry matter is equivalent to 1.77 acre inches per ton of dry matter.
300 lb. of water for 1 lb. of dry matter is equivalent to 2.64 acre inches per ton of dry matter.
400 lb. of water for 1 lb. of dry matter is equivalent to 3.53 acre inches per ton of dry matter.
500 lb. of water for 1 lb. of dry matter is equivalent to 4.42 acre inches per ton of dry matter.
1000 lb. of water for 1 lb. of dry matter is equivalent to 8.85 acre inches per ton of dry matter.

EVAPORATION OF SOIL MOISTURE FROM IRRIGATED LANDS

The rate of soil moisture evaporation is influenced by the temperature of the air and soil, the amount of air currents, the exposure to sunshine, the dryness of the air, the degree of saturation of the surface of the soil, and the texture and character of the soil. The effects of these various factors have been investigated, through interesting experiments made in the arid region by the Irrigation Investigations of the U. S. Department of Agriculture, the Utah Agricultural College, and others. The most comprehensive set of experiments are those carried on by the Irrigation Investigations at seven typical stations of the arid region, from 1908 to 1910. Many of the observations and

most of the diagrams presented below are taken from Bulletin 248 of the Office of Experiment Station, U. S. Department of Agriculture, on Evaporation from Irrigated Soils, which embody the results of this set of experiments. The results were obtained in most cases by means of tanks or pots filled with soil and placed as nearly as possible under field conditions of irrigation and cultivation (Plate I, Fig. A.) While the results obtained do not justify accurate numerical conclusions, they are of great value in indicating how some of the factors affecting evaporation loss can be controlled by proper irrigation and cultivation methods.

EXTENT OF EVAPORATION FROM BARE SOILS AND EFFECT OF SOIL SATURATION

On four Southern California orchard soils, not cultivated and receiving a total average depth of irrigation water of 14 3/4 inches in five irrigations, the first one being 6.7 inches in depth, the evaporation loss for the season (Feb. 23–Aug. 31) was 94 per cent. of the water applied.

The effects of soil saturation and the comparative results of soil moisture evaporation from bare soils not cultivated with those of evaporation from a free water surface are illustrated by the following examples:

EFFECT OF SOIL SATURATION ON EVAPORATION OF SOIL MOISTURE

Soil	Degree of saturation per cent. free moisture by weight	Weekly evaporation from soil surface, inches	Weekly evaporation from free water surface, inches
Sandy loam, Cal.	Saturated	4.75	1.88
Sandy loam, Cal.	17.5	1.33	1.94
Sandy loam, Cal.	11.9	1.15	1.94
Sandy loam, Cal.	8.9	0.88	1.94
Sandy loam, Cal.	4.8	0.25	1.94
Fertile sandy loam, Utah	15.67	1.35	......
Fertile sandy loam, Utah	10.67	0.50	
Fertile sandy loam, Utah	5.67	0.27	

The rate of evaporation for a period of 28 days from uncultivated, bare soil surfaces and from a free water surface, as obtained from the average results at six stations in the arid region, are shown in the accompanying diagram (Fig. 1).

The large rate of evaporation from soils which are nearly

EFFECT OF SOIL SATURATION ON EVAPORATION OF SOIL MOISTURE

Soil	Per cent. free moisture at beginning	Evaporation for period of 3 weeks in inches		Period
		From soil surface	From free water surface	
Rich silty loam, Bozeman, Montana	22.3	2.86	4.53	Sept. 2–28, 1908
Rich brown sandy loam Davis, Cal.	8.8	1.62	8.02	June 10–July 1, 1908
Sandy alluvial loam, Reno, Nev	7.2	1.41	4.68	Sept. 1–22, 1908
Sandy loam, Wenatchee, Wash	6.2	0.86	6.12	June 3–24, 1908
		Same for	4 weeks	
Rich silty loam, Bozeman, Montana	17.80	2.92	4.38	July 25–Aug. 22, 1909
Rich brown sandy loam Davis, Cal.	12.85	1.91	9.41	May 5–June 2, 1909 June 5–July 3, 1909
Sandy alluvial loam, Reno, Nev.	8.88	1.51	8.49	May 7–June 4, 1909 June 8–July 6, 1909
Sandy loam, Sunnyside, Wash.	6.0	2.47	7.25	May 18–June 15, 1909

saturated indicates the necessity for wetting as little of the surface soil as possible when irrigating. For orchards and crops which are irrigated by means of furrows, the advantage of using deep furrows is apparent. The heavy loss of water from the soil during the first 3 days following the irrigation shows the necessity of early cultivation to decrease the loss.

EFFECT OF MULCHES OF DIFFERENT DEPTHS

Six inches depth of water was applied to the surface of the soil in the tanks by the flooding method; when this had sunk into the soil, dry soil mulches of different depths were added to some of the soil surfaces. The losses by evaporation were obtained by semi-weekly weighings for a period of 3 weeks. The average of the results obtained are shown by the accompanying diagram (Fig. 2).

The average numerical results are shown by the following table:

FIG. A.—Tanks used for experiments on soil evaporation.

FIG. B.—Levelling the land surface with Fresno scraper.

(*Facing Page* 18.)

EFFECT OF MULCHES OF DIFFERENT DEPTHS ON SOIL MOISTURE EVAPORATION

Condition of soil	Evaporation loss		Per cent. of saving on evaporation from unmulched soil
	Inches	Per cent. of water applied	
No mulch................	1.75	29.2	....
3-inch mulch..............	0.75	12.5	57.0
6-inch mulch..............	0.34	5.7	81.0
9-inch mulch..............	0.22	3.65	87.5

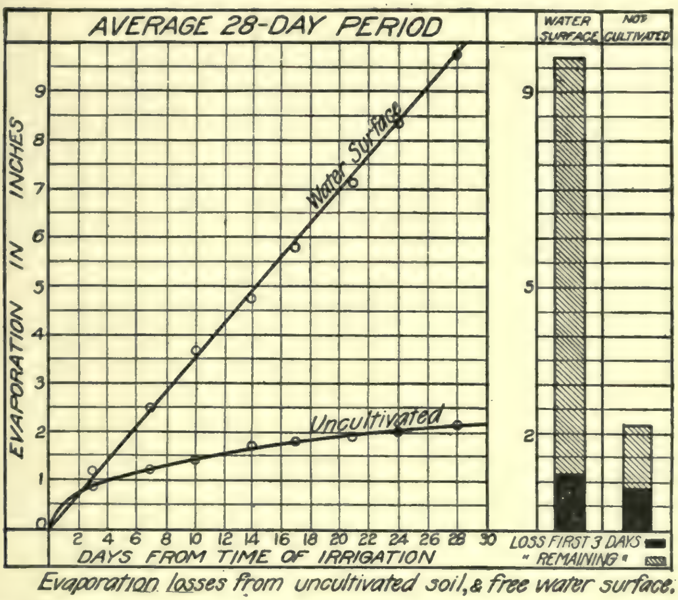


FIG. 1.—Evaporation loss from uncultivated bare soils, for a period of 28 days, following the application of 6-in depth of water on the surface and from a free water surface for the same period. The loss from soils is the average measured at six stations in the arid region; the loss from water surface is the average at four of these stations.

The saving in soil evaporation due to mulches is well shown by the figures in the last column. These experiments represent, however, ideal conditions which are seldom obtained in practice.

EFFECT OF SOIL MULCHES PRODUCED BY CULTIVATION

The experiments to determine this effect were made so as to approach ordinary field conditions and practice as nearly as

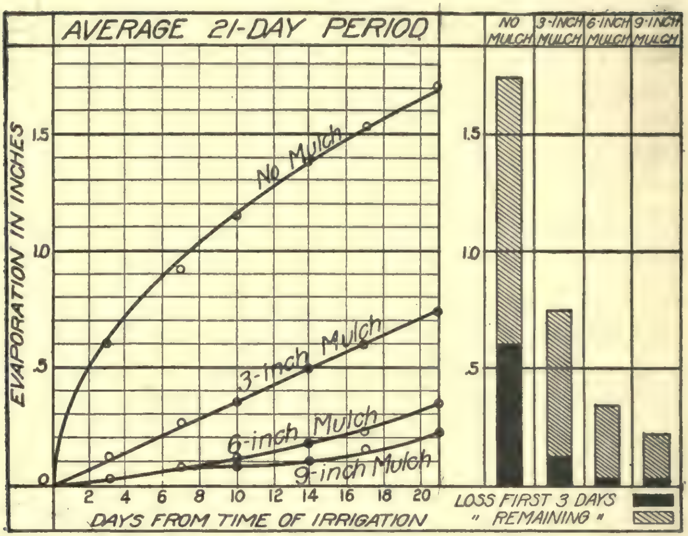


Fig. 2.—Average evaporation loss from soils, protected with mulches of different depths, for a period of 21 days, following the application of 6 inches depth of water on the surface. The results are the average obtained at five stations.

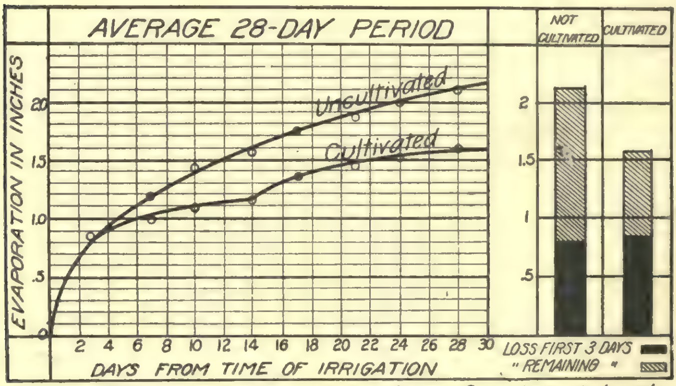


Fig. 3.—Evaporation loss from cultivated and uncultivated soils, for a period of 28 days, following the application of 6 inches depth of water on the surface. The results are the average obtained at six stations.

possible. A 6-inch depth of irrigation was applied to the surface. Depending on the texture of the soil, it took from 6 to 24 hours for the water to disappear from the surface; as soon as the condition of the soil permitted, averaging about 3 days and ranging from 1 to 4 days after the irrigation, the soil in the tanks was cultivated to a depth of 6 inches. A second cultivation was given 2 weeks after the irrigation. The average of the results obtained at six stations are illustrated by the accompanying diagram (Fig. 3).

The total average evaporation loss in 28 days from the uncultivated soil was 2.14 inches or 35 per cent. of the water applied. Cultivation caused a saving equal to 26 per cent. of the loss obtained with no cultivation. The saving due to cultivation is influenced by the moisture condition of the surface soil; where rain fell during the experiment, the effects of cultivation were not so beneficial. This is shown by the following tabulated results:

EFFECTS OF CULTIVATION ON SOIL MOISTURE EVAPORATION

Locality	Total rainfall, inches	Free water in soil before irrigation, per cent.	Evaporation from free water surface, inches	Loss from cultivated soil; inches	Loss from uncultivated soil, inches	Loss saved by cultivation, per cent.
Sunnyside, Wash.	0.00	6.00	7.25	1.47	2.47	40.3
Davis, Cal	0.00	12.85	9.41	1.36	1.91	28.2
Reno, Nevada	0.39	8.88	8.49	1.09	1.51	27.8
Caldwell, Idaho	0.14	6.21	9.81	1.91	2.42	21.0
Agricultural College, New Mexico	0.57	....	11.13	1.37	1.59	13.8
Bozeman, Montana	0.99	17.80	4.38	2.30	2.92	21.2
				1.58	2.14	26.4

The effects of different depths of cultivation were obtained by experiments carried on at Davis, California, for two periods of 28 days each. The average evaporation loss during a 28 day period for no cultivation, for cultivation 2 inches deep, 4 inches deep, and 6 inches deep was 2.22 inches, 1.75 inches, 1.35 inches, and 1.31 inches, respectively. A 4-inch cultivation was nearly as efficient as a 6-inch cultivation, and saved 39.2 per cent. of the evaporation loss. At some of the other stations, where rainfall occurred during the experiments and where cultivation

followed each shower, the exposure of moist soil by deep cultivation increased the evaporation loss.

EFFECT OF DEPTH OF FURROWS

The experiments carried on to demonstrate the influence of depth of furrows on soil evaporation imitated as nearly as possible field practice. The tanks received a 6-inch depth of irrigation water. As soon as practicable this was followed by a cultivation 6 inches deep. The average results obtained at Davis, Cal., and Reno, Nevada, where rainfall did not interfere with the efficiency of deep irrigation and cultivation, are shown by the accompanying diagram (Fig. 4.)

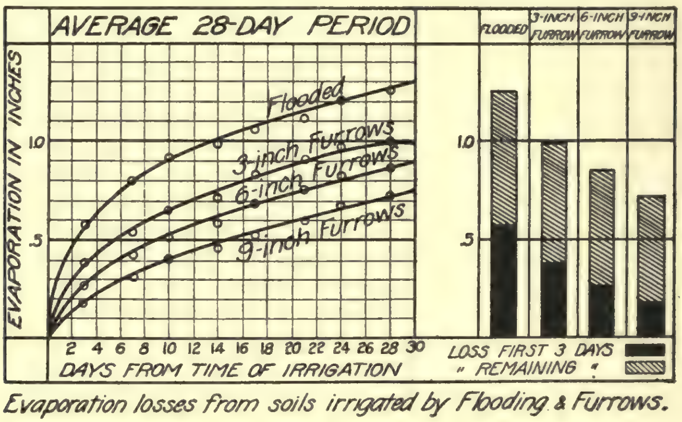


Fig. 4.—Evaporation loss from soils irrigated by flooding and by furrows of different depths. The results are the average obtained at two stations.

The respective evaporation losses during a period of 28 days from soils, surface flooded and irrigated in furrows 3, 6, and 9 inches deep, were 1.25 inches, 0.99 inches, 0.86 inches, and 0.72 inches. The use of 9-inch furrows saved 42.4 per cent. of the loss obtained with surface flooding and 26.5 per cent. of the loss obtained with 3-inch furrows. Nearly all the saving produced by furrow irrigation was in the first week after irrigation.

At the other stations the effects of depth of furrow irrigation and of cultivation were counterbalanced by the wetting of the surface soil by the rainfall occurring during the experiments, and there was very little difference in the evaporation losses.

EFFECTS OF SHADE ON SOIL MOISTURE EVAPORATION

Experiments made in Utah show that the evaporation from the surface of a bare sandy loam, containing 20 per cent. total moisture, was decreased 29 per cent. when wholly shaded.

EFFECTS OF TEMPERATURE, SUNSHINE, AND HUMIDITY ON SOIL MOISTURE EVAPORATION

The following results obtained in Utah show the combined effect of these factors on the soil moisture evaporation from a soil of 8 feet in depth.

Average number of days	Total moisture at beginning, per cent.	Loss of water		Temp. Fahr.	Relative humidity, per cent.	Hours of sunshine
		In lb. per sq. ft.	In inches.			
10	15.66	11.99	2.3	66	54	89
10	15.69	15.04	2.9	73	48	101

An increase of 7° in temperature and of 12 hours of sunshine, with a decrease of 6 per cent. in humidity, increased the evaporation loss 25 per cent.

PERCOLATION OF WATER APPLIED TO THE SOIL

When irrigation water is applied to a soil, the surface in contact with the water is saturated. A portion of this water is lost by evaporation, the remainder moves downward by gravity and laterally by capillarity, furnishing the necessary free moisture to the plant roots. When only a small amount of water has been applied, this may be all retained in the zone of soil which contains the bulk of the root system. When a larger quantity is applied, the excess water passes down beyond the reach of the roots and is wasted. This is illustrated by the results of experiments made in Utah, given above on page 9. These experiments, which were made on a fertile sandy loam, show that when 2.5 inches depth of irrigation water was applied, all of it was found in the upper 8 feet of soil the first day after irrigation, while when 5.0 inches and 7.5 inches were applied the quantities retained in the first 8 feet of soil were 77 per cent. and 69 per cent., respectively. Mr. Don H. Bark, in charge of Irrigation Investigations in Idaho

for the U. S. Department of Agriculture, made experiments to determine the loss by percolation on a gravelly loam underlaid with a very gravelly subsoil. The soil was taken from a field and placed in a tank 2 feet in diameter and 6 feet deep, as nearly as possible in its original position, and seeded to alfalfa. Water was applied to the surface at the same rate and at the same time as used in actual practice on the field. The results obtained are shown in the accompanying table.

PERCOLATION FROM GRAVELLY SOIL, 6 FEET DEEP, PLACED IN TANK AND SEEDED TO ALFALFA. SEASON, 1911

Date	Depth applied to tank, feet.	Time required for absorption	Depth of water lost by percolation, feet	Time required for percolation	Per cent. of loss by deep percolation
May 31.......	1.099	2 hr. 50 min.	0.686	13 days	62.4
June 14.......	0.710	1 hr. 28 min.	0.662	5 days	93.2
July 8........	0.829	52 min.	0.795	9 days	95.8
Aug. 1........	0.642	10 min.	0.513	8 days	79.8
Aug. 9........	1.090	33 min.	0.965	5 days	88.5
Aug. 31.......	1.143	47 min.	0.944	6 days	82.5
Sept. 24......	1.085	56 min.	0.946	3 days	87.1
Total........	6.599	....	5.511	....	83.51
Precipitation June–Sept....	0.309	....	....	....	....

This experiment showed that 83.5 per cent. of the water applied passed beyond the 6-foot depth and was lost by deep percolation. An average of about 1.8 inches was retained at each irrigation; this lead to a continuation of the experiment the following season, whereby the tank received a first irrigation of 0.297 foot depth, followed by frequent light irrigations, averaging about 0.148 foot (1.8 inches) applied when the alfalfa showed the need of it. The results are tabulated in the accompanying tables.

The yield of alfalfa planted in the tank was equivalent to 7.147 tons of cured hay per acre, which was considerably more than usually obtained in actual practice. This experiment showed that, for this type of soil, the proper depth of irrigation to eliminate percolation loss was about 1.8 inches. Were it possible to apply this depth of water by the usual methods of irrigation without deep percolation losses on some parts of the field, the quantity of water required to produce a crop on a gravelly soil of this type would not be greater than for a more retentive soil; the open soil would require light irrigations applied frequently,

while the more retentive soil would retain a greater volume of irrigation water and would require less frequent irrigations.

PERCOLATION FROM GRAVELLY SOIL, 6 FEET DEEP, PLACED IN TANK AND SEEDED TO ALFALFA. SEASON, 1912

Date	Total depth applied, feet	Depth of water lost by percolation, feet	Depth retained by tank, feet
May 28	0.297	0.122	0.175
June 21	0.148	Trace	0.148
July 2	0.149	Trace	0.149
July 6	0.148	0.0	0.148
July 13	0.149	0.0	0.149
July 21	0.148	0.0	0.148
July 28	0.149	0.0	0.149
Aug. 8	0.148	0.0	0.148
Aug. 13	0.149	0.0	0.149
Sept. 2	0.148	0.0	0.148
Total	1.633	0.122	1.511
Precipitation, April–Aug	0.71	...	...

EFFECT OF LENGTH OF RUN OF WATER IN FIELD FLOODING ON DEEP PERCOLATION

One of the common methods of irrigating cereals or alfalfa, where the land is smooth and on a flat slope, consists in spreading a sheet of water over the field, which is prepared in long narrow strips 30 to 100 feet wide and from 300 feet to as much as half a mile long in extreme cases; the length runs usually in the direction of the steepest slope, unless the slope is excessive when the length runs diagonally and the water is turned in at the upper end. In actual practice the upper end of the field is very likely to receive a large excess of irrigation water, which is lost by deep percolation. This loss will depend chiefly on the slope of the land, the length of field or run, the texture of the soil, and the head of water (or rate of flow) turned in at the upper end. Where a small head is used and the length of run is large, the loss in open soil may be very great, and in some cases the sheet of water may not reach the lower end.

The effect of the length of runs is well illustrated by the following experiment, made in Idaho, by Don H. Bark: A strip of clover, 49.5 feet wide and 2,359 feet long, was considered in seven equal divisions 337 feet long. A constant head of about 3 cubic feet per second was turned in at the upper end, and the length of

time required for the sheet of water to travel to the lower end of each strip and thoroughly irrigate it was noted. The results are tabulated below:

EFFECT OF LENGTH OF RUN OF WATER IN FIELD FLOODING ON DEEP PERCOLATION

Division number	Length of run, feet	Area irrigated, acres	Time required		Acre, feet applied.	Average depth in feet
			Hours	Minutes		
1	337	0.38	1	7	0.28	0.73
1–2	674	0.77	2	30	0.63	0.82
1–3	1,011	1.15	4	00	1.01	0.88
1–4	1,348	1.53	5	40	1.43	0.93
1–5	1,685	1.92	8	25	2.12	1.11
1–6	2,022	2.30	11	30	2.90	1.26
1–7	2,359	2.68	15	40	3.95	1.47

These results show that to irrigate thoroughly this strip of land with a run 2,359 feet long, it required an average depth of irrigation water over the field of 1.471 feet; while, if the field had been divided into runs, one-seventh of the above run, by the construction of six additional supply ditches, the average depth of irrigation would have been only 0.733 feet or 50 per cent. of the water used with longer runs. The length of irrigation period for the larger run was 15 hours and 40 minutes, while with the shorter run the total time would have been seven times the irrigation period of the shorter run, or 7 hours and 49 minutes—a decrease in time of 50 per cent. A similar experiment was made on a strip of alfalfa, 92 feet wide and 2,565.9 feet long, divided into seven equal parts, each 326.7 feet long, with a shorter division at the lower end 269 feet long. A head of 7 cubic feet per second was maintained at the upper end. The results are tabulated below.

EFFECT OF LENGTH OF RUN OF WATER IN FIELD FLOODING ON DEEP PERCOLATION

Division number	Length of run, feet	Area irrigated, acres	Time required		Acre, feet applied	Average depth in feet
			Hours	Minutes		
1	327	0.70	0	45	0.43	0.62
1–2	653	1.41	1	40	0.96	0.68
1–3	980	2.13	2	50	1.63	0.76
1–4	1,307	2.88	4	15	2.44	0.85
1–5	1,634	3.63	6	15	3.59	0.99
1–6	1,960	4.39	8	15	4.74	1.08
1–7	2,287	5.17	10	30	6.04	1.17
1–8	2,566	5.72	13	15	7.62	1.33

The above table shows that, by dividing the field into runs one-eighth of the length of the field by the construction of seven supply ditches across it, the average depth of irrigation would have been 0.617 feet as compared to 1.332 feet for the single longer run. The time required to irrigate for the shorter run, using the same head in turn in each of the cross ditches, would have been about

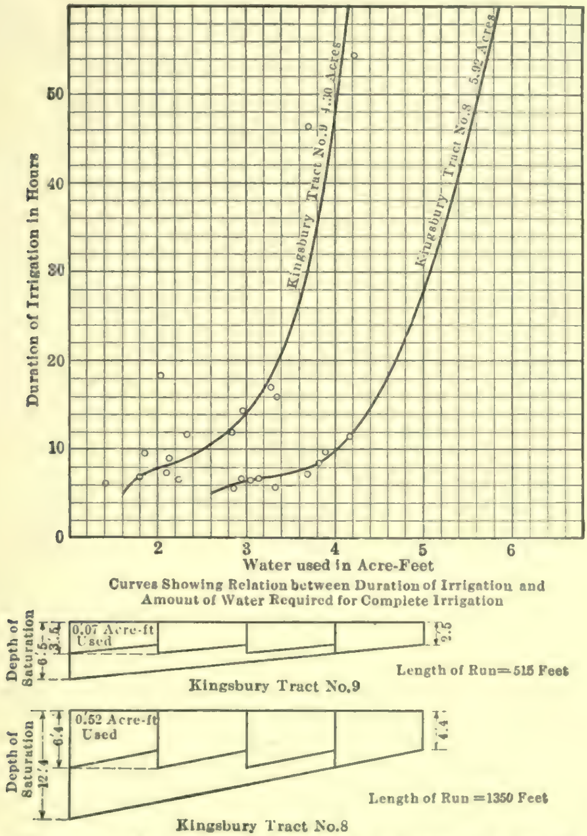


FIG. 5.—Diagrams showing loss of water by excessive length of run.

6 hours instead of 13 hours and 15 minutes with the longer run. Similar experiments, to show the effect on loss by deep percolation of the length of run, head of water or duration of irrigation, were conducted in the Boise Valley, Idaho, by the U. S. Reclamation Service during 1910 and 1911. The results as summarized by curves and diagrams are reproduced above.

The effect of the length of run was determined by experiments on two tracts, denoted by Tracts No. 8 and No. 9 on Kingsburg Ranch. Tract No. 8 contains 5.92 acres; the soil is wind-blown ash and sand underlaid with sand and gravel; the length of run was 1,350 feet. Tract No. 9 contains 4.30 acres, the soil is a thin layer of ash and sand underlaid with very porous coarse gravel, and the length of run was 515 feet. The results are shown in the diagram Fig. 5. The area above the lower sloping line represents the depth of saturation and the volume of water used when the tract was irrigated by a single length of run. The area above the broken line shows the depth of ground saturation and indirectly the volume of water used for runs one-fourth of the single length of run. For tract No. 8 and for irrigation by single length of run, the volume of water used was 3.25 acre-feet; for runs of one-fourth the length, the volume is 2.08 acre-feet; the longer run required 54 per cent. more water than the shorter runs. For tract No. 9, irrigation by a single run required 0.39 acre-feet, and by runs one-fourth of the length 0.29 acre-feet; the longer run required 35 per cent. more water.

The relation between the number of acre-feet on the entire tract required to obtain a complete irrigation, and the duration of the irrigation which depends on the head of water used, are shown by the curves in the diagram. For instance, when tract No. 8 is irrigated in 5 hours, it requires 2.6 acre-feet for 5.92 acres, or about 5.25 inches in depth of water and the corresponding head is 6.25 cubic feet per second; when irrigated in 10 hours, the depth is 8.1 inches and the corresponding head 4.8 cubic feet per second, and in 60 hours the depth of water was 12 inches and the head 1.17 cubic feet per second. By using the large head for 5 hours it required 65 per cent. and 44 per cent., respectively, of the volume of water required to obtain a satisfactory irrigation with smaller heads for 10 and 60 hours. The results obtained on these tracts, with those obtained on a third tract in the Boise Valley, representing three kinds of soil and three lengths of run, are worked out into two sets of curves, shown in the diagram, Fig. 6. One set of curves shows the relation between the duration of the irrigation period and the head of water in miners' inches per acre; the other set of curves gives the duration of the irrigation period and the corresponding volume of water used in acre-feet per acre to obtain a satisfactory irrigation. The curves show

that decreasing the size of the irrigating head, causes a proportionately larger increase in the time necessary to obtain a

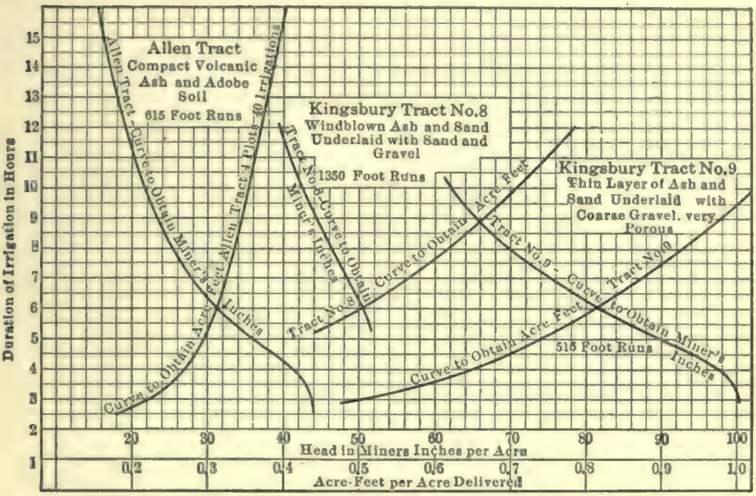


FIG. 6.—Curves showing the relation between the duration of irrigation in hours, the head in miner's inches per acre, and the delivery in acre-feet per acre for soils of different character.

complete irrigation, and therefore requires a greater depth of irrigation water per acre and a greater loss by deep percolation.

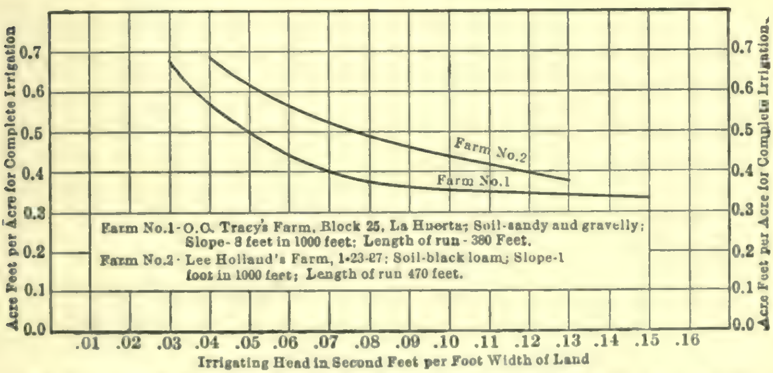


FIG. 7.—Effect of head of water on depth of irrigation in flooding by border method. Carlsbad Project, New Mexico.

On the Carlsbad project in New Mexico the Reclamation Service made a number of experiments to show the effect of the

size of the irrigating head on the depth of water required to obtain a complete irrigation. These experiments were made on a number of farms, which gave soils of different characters and land surfaces of different slopes and different lengths of run. The results all show the value of using large heads in decreasing the deep percolation loss, by getting the water over the land quickly. This is illustrated by the plotted results for two representative experiments, (Fig. 7). In both cases the quantity of water applied to obtain a complete irrigation is about 1/2 as much for the largest head used as for the smallest head. The soil of Farm No. 1 is sandy gravelly soil; as compared with the soil of Farm No. 2 it is more porous, but its slope is greater and the length of run or distance the water has to travel is shorter; these conditions probably account for the comparatively small amount of water required for one complete irrigation on the porous soil of Farm No. 1.

Experiments made by the Irrigation Investigations of the U. S. Department of Agriculture have, according to Mr. Tallman, proved conclusively that fully 50 to 75 per cent. of the water applied to the gravelly soils of the Upper Snake Valley in Idaho is lost by deep percolation beyond the reach of plant roots.

PERCOLATION OF WATER APPLIED IN FURROWS

The percolation of water from furrows in orchard irrigation has been studied by Professor Loughridge through experiments carried on in Southern California citrus orchards for the Irrigation Investigations of the U. S. Department of Agriculture. The method pursued to determine the percolation was as follows:

Cross trenches were dug across several furrows to a depth of 5 or 6 feet; the furrows were extended over the trench by short wooden troughs. At regular periods during irrigation a thin slice of soil was cut from the face of the trench exposing a fresh surface of the wet area. The outlines were measured and recorded during and after the period of irrigation. The accompanying diagrams give the percentage of free moisture in the soil and show by irregular curves the depth of percolation at different times.

The first diagram, Fig. 8, is for a sandy loam soil, 7 to 9 feet deep, underlaid with a sandy soil. The observations were made

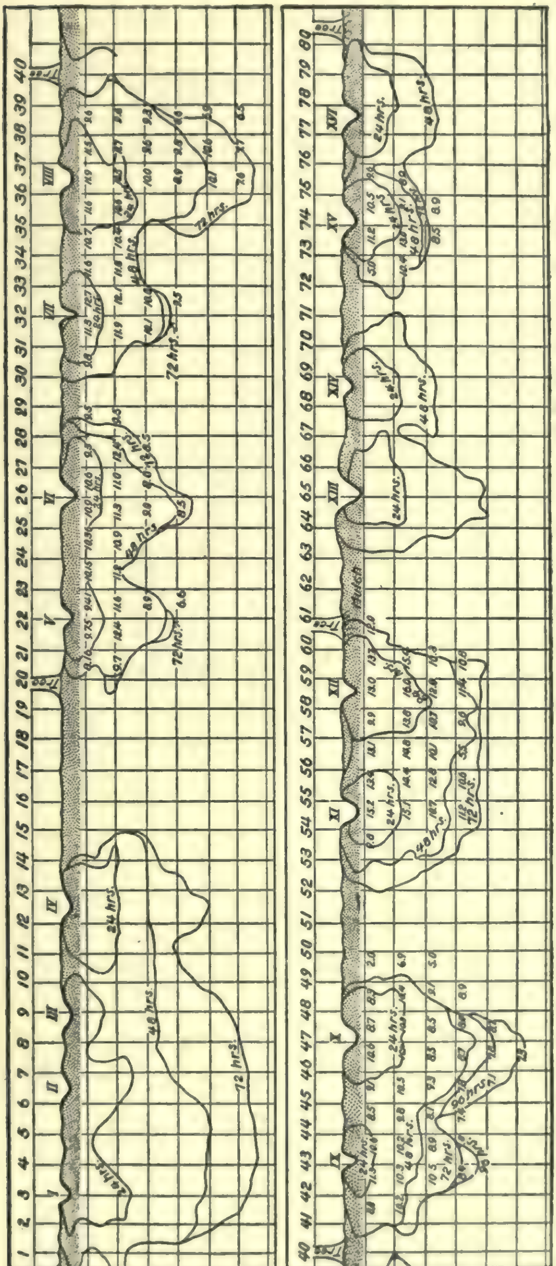


FIG. 8.—Outlines of percolation under sixteen furrows in sandy loam. From O. E. S. Bull. 203, U. S. Dept. of Agriculture.

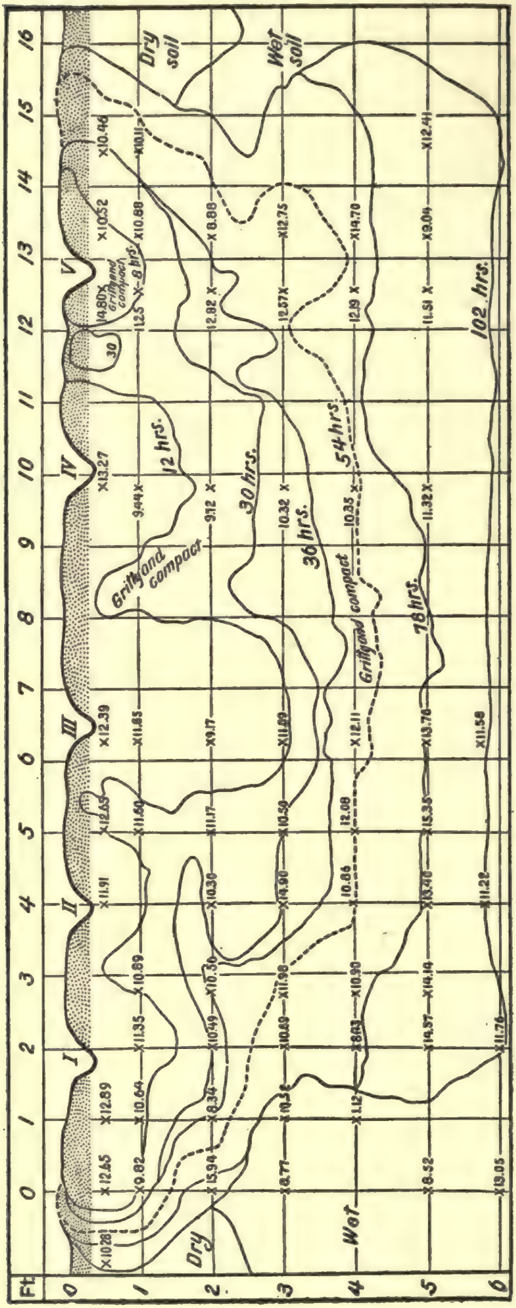
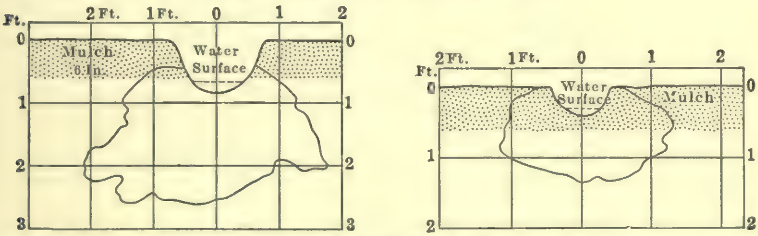


FIG. 9.—Outlines of percolation under five furrows in gritty clay loam. From O. E. S. Bull. 203, U. S. Dept. of Agriculture.

in a trench excavated across sixteen furrows. The furrows were 660 feet long and the trench was half-way down the furrows; it required about 5 hours for the water to travel half the length of the furrows and about 12 hours more to reach the end. This diagram shows results which are very surprising to the irrigator. It is commonly believed that the water spreads laterally so as to give a fairly uniform distribution throughout the soil, but the diagram shows that the water spreads only a small distance laterally, usually less than 3 feet from the furrows, which is not sufficient to wet the soil uniformly. In the first foot 77 per cent. of the soil was wetted, in the second foot 78.75 per cent., in the third foot 71.13 per cent., in the fourth foot 40 per cent., in the fifth 27.50 per cent., and in the sixth 5 per cent. This shows the necessity for placing the furrows close to the trees and for having a sufficient number of furrows to bring them close together.



FIGS. 10 AND 11.—Outlines of percolation from furrow 10 inches and 5 inches deep, in seven hours. From O. E. S. Bull. 203, U. S. Dept. of Agriculture.

The next diagram, Fig. 9, is for a gritty clay loam with a subsoil which is very compact, but which quickly absorbs water and becomes soft. The trench was made across five furrows half-way down the furrows. At the end of 54 hours the water was cut off. The distribution of water in this soil was much more uniform than in the previous case. This is due to the soil being more compact, which produces a slower downward percolation and a greater sideways motion because of the greater effect of capillarity.

The third and fourth diagrams, Figs. 10 and 11, show the limit of percolation in a sandy soil from single furrows 10 inches deep and 5 inches deep for a period of 7 hours. With the deep furrows there is a greater depth of percolation and the water spreads farther sideways. The deep furrow also has the advan-

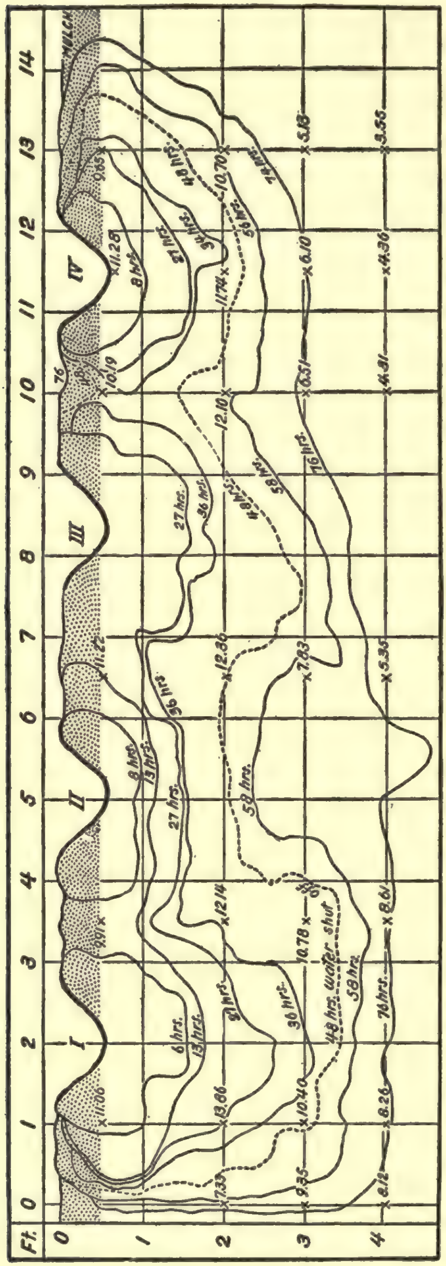


FIG. 12.—Outlines of percolation under four deep furrows in heavy loam. From O. E. S. Bull. 203, U. S. Dept. of Agriculture.

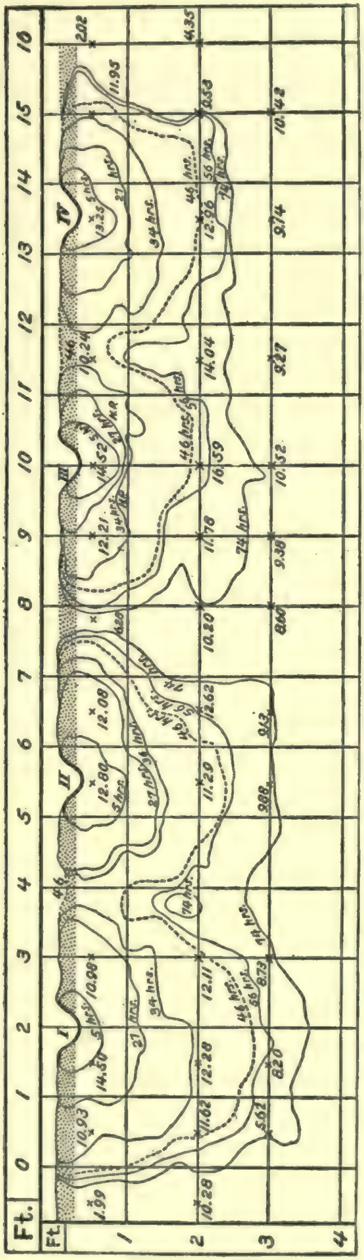


FIG. 13.—Outlines of percolation under four shallow furrows in heavy loam. From O. E. S. Bull. 203, U. S. Dept. of Agriculture.

tage that less of the surface mulch is wetter than with shallow furrows.

The fifth and sixth diagrams, Figs. 12 and 13, show the outlines of percolation in heavy loam for four deep and four shallow furrows under the same conditions of soil and water. The deep furrow gives a more uniform distribution of water, a greater depth of percolation, a greater sideways absorption, and a smaller percentage of moisture rises by capillarity to the surface to be lost by evaporation.

The seventh diagram, Fig. 14, shows the probable distribution of moisture in a sandy loam lengthwise with the furrows, from the head to the foot of the furrows as determined by a few borings. The furrows are 660 feet long and the water was run in them for a period of 3 days. Sufficient borings were not taken to determine the curve accurately. Other experiments showed that the curve may ascend quite abruptly toward the surface, as indicated by the dotted line. This diagram shows clearly that the water is

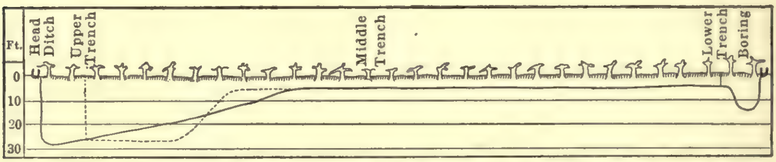


FIG. 14.—Curve showing probable lower limit of percolation from head to foot of furrows in sandy loam. From O. E. S. Bull. 203, U. S. Dept. of Agriculture.

not evenly distributed; the depth of percolation near the head ditch is much greater than the average depth of percolation along the furrow; a large part of the water passes beyond the reach of plant roots and is wasted. With heavy soils the difference in percolation would not be so great. This experiment shows the necessity for short furrows, especially in sandy soils.

SURFACE RUN-OFF OR WASTE

This loss represents a waste, the extent of which is dependent on the skill and care taken in the preparation of the land for irrigation and in the application of the water. On many farms this loss does not exist, but it is frequently not prevented. On eight of the projects of the U. S. Reclamation Service, in the

Northern Division (Montana, North Dakota, Wyoming) the loss averaged about 8 per cent. of the water applied. On the Boise project the run-off for nine tracts of grain and alfalfa ranged from 4 to 18 per cent., averaging 11 per cent. of the water applied. Investigations made by Don H. Bark in Idaho show that on clay loam the surface waste was 21.3 per cent. and 16.1 per cent. respectively for alfalfa and grain; on gravelly soil there was practically no surface waste.

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CHAPTER III

WATER REQUIREMENT OF IRRIGATED CROPS

Investigations carried on in California, Idaho, Montana, and Utah indicate that the yield of crops does not depend entirely on the quantity of water, but on the time when it is applied. It has been found that, when the water is properly applied so as to eliminate controllable losses, different quantities of water will give different crop yields, but that the increase in yield is not in direct proportion to the increase in quantity of water applied and for some crops at least there is a total depth of water which will give a maximum yield, and any quantity in excess of this is not only wasted but decreases the yield, the plants suffering because of the excess moisture. With all crops, even before this maximum yield water requirement is obtained, the increase in yield is small in proportion to the increased use of water and economical considerations, such as the value of the extra water, and the value of the corresponding net return of the increased yield will limit the best use of water to a smaller quantity than the water requirement for maximum yield, which may be called *the economical beneficial use of water.*

The water requirement for maximum yield has been fairly well determined for some crops by experiments in applying different quantities of water, following the best methods of irrigation and cultivation used in actual practice, to eliminate as much as practicable unnecessary losses.

WATER REQUIREMENT OF ALFALFA FOR MAXIMUM YIELD

Dr. Fortier in 1903, when director of the Montana Experiment Station, made experiments on seven plots of alfalfa. The results obtained are given in the following table, taken from Farmers' Bulletin 373 on Irrigation of Alfalfa (U. S. Department of Agriculture).

QUANTITIES OF WATER APPLIED TO ALFALFA AND YIELDS SECURED, MONTANA EXPERIMENT STATION

Plot number	Depth of irrigation	Depth of rainfall	Total depth	Yield per acre of cured alfalfa
1	0.5 ft.	0.70 ft.	1.20 ft.	4.61 tons
2	None	0.70	0.70	1.95
3	1.0	0.70	1.70	4.42
4	1.5	0.70	2.20	3.75
5	2.0	0.70	2.70	6.35
6	2.5	0.70	3.20	7.20
7	3.0	0.70	3.70	7.68

The Irrigation Investigations of the U. S. Department of Agriculture has made experiments on about thirty plots of alfalfa at the University Farm at Davis, California, to determine the best use of water on alfalfa. The yields obtained for the varying amounts of water are as follows:

QUANTITIES OF WATER APPLIED TO ALFALFA AND YIELDS SECURED AT DAVIS, CALIFORNIA

Depth of irrigation water applied, inches	Schedule of irrigation in 1912	Yield in tons per acre		
		1910	1911	1912
None	....	3.85	6.02	5.52
12	6″ after 1st and 2nd cutting...	4.75	7.52	6.51
18	6″ after 1, 2, 3 cutting........	....	....	7.02
24	6″ after 1, 2, 3, 4 cutting.....	6.00	8.38	8.32
30	7½″ after 1, 2, 3, 4 cutting.....	7.53	9.61	9.43
32	....	....	9.20	....
36	9″ after 1, 2, 3, 4 cutting.....	7.58	9.33	9.38
48	12″ after 1, 2, 3, 4 cutting....	8.45	9.64	8.87
60	12″ after 1, 2, 3, 4, 5 cutting....	....	....	10.04

The alfalfa was planted in the spring of 1909, and re-seeded after disking and harrowing in the spring of 1910. The rainfall during the fall, winter, and spring preceding the summer of 1910, 1911, and 1912 was 12 inches, 23 inches, and 9.46 inches, respectively. The rainfall during the growing season from the beginning of April to the end of October, for all 3 years, was less than 1 inch. The soil was a sandy loam of great depth, and the substantial yields obtained without irrigation are due to the winter and spring rainfall retained in the soil. The results (Fig. 15) show that the yield increases with a proportionate greater increase in the amount of water applied up to a depth of 30 inches, which gave very nearly maximum yield for all 3 years.

Mr. Don H. Bark, in charge of Irrigation Investigations in Idaho, has carried on during the seasons of 1910, 1911, and 1912 some interesting experiments on the water requirements of a number of irrigated crops. The method used was to select fields, averaging about 12 acres, on a large number of typical farms of the State. These fields were divided in about three equal parts. On one part the owner used the same manner of irrigation and

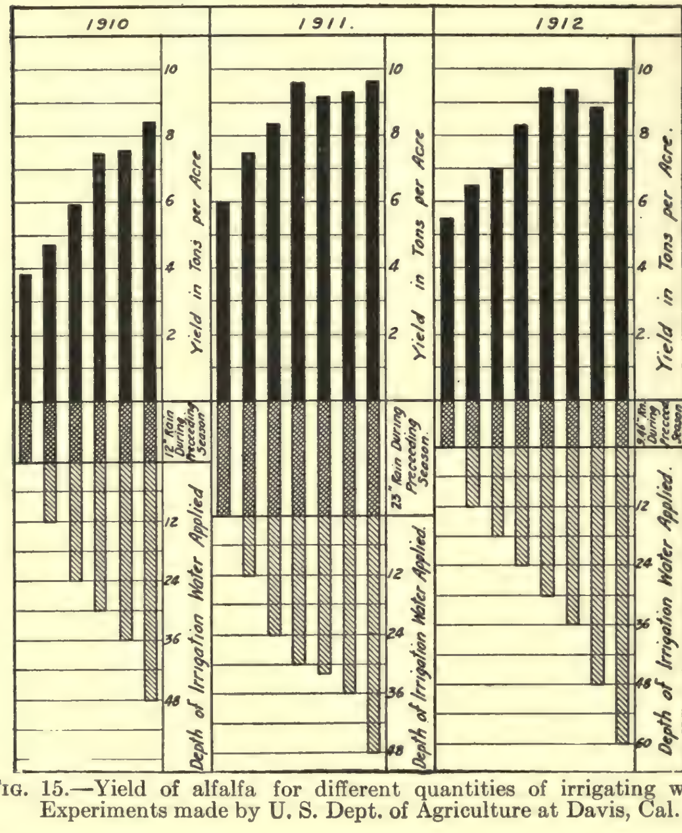

FIG. 15.—Yield of alfalfa for different quantities of irrigating water. Experiments made by U. S. Dept. of Agriculture at Davis, Cal.

same quantity of water as had been his custom. On the second part a greater amount was used, and on the third part a smaller amount. Measurements of the water applied and of the yields obtained on ninety-three of these subdivisions have enabled Mr. Bark to reach the following average values for the quantity of water which gave the best yields:

WATER USED IN IDAHO FOR BEST YIELDS OF ALFALFA

Class of soil	Season	Depth of water applied in feet	Average
Medium clay and sandy loam soils..	1910	2.54	....
	1911	2.783	....
	1912	2.160	2.50
Porous sandy and gravelly soil.....	1910	7.130	....
	1911	6.500	6.815

YIELD OF ALFALFA FOR DIFFERENT QUANTITIES OF IRRIGATION WATER

(Idaho)

Class of soil	Locality	Year	No. of irrigations	Precipitation, April to Sept. inclusive	Depth of irrigation water in feet	Yield per acre in tons	Remarks, length of run
				inches			
Very gravelly...	Rigby, Idaho.....	1910	4	2.36	6.352	3.78	1979 to 2550
			6	2.36	6.925	3.65	1979 to 2550
			7	2.36	9.401	5.20	1979 to 2550
Very gravelly with porous sub-soil.	Rigby, Idaho.....	1911	4	6.95	5.402	1.99	....
			7	6.95	6.400	3.42	....
			6	6.95	7.224	3.27	....
Porous gravelly..	Rigby, Idaho.....	1912	4	8.51	3.047	1.82	300 ft.
			4	8.51	3.307	2.00	530 ft.
			4	8.51	6.721	2.50	1500 ft.
Medium clay loam.	Gooding Exp. Sta.	1910	2	1.85	1.306	3.30	....
			3	1.85	1.872	3.56	....
			3	1.85	2.104	4.74	....
Medium clay loam.	Gooding Exp. Sta.	1911	3	3.98	1.775	3.77	....
			6	3.98	3.329	5.30	....
			8	3.98	4.000	6.61	....
Medium clay loam.	Gooding Exp. Sta.	1912	2	3.47	0.615	2.85	....
			4	3.47	1.308	4.00	....
			7	3.47	2.059	5.41	....
			9	3.47	2.533	5.66	....
			11	3.47	2.931	6.25	....
			13	3.47	4.003	6.30	....
Medium clay loam.	Kimberly, Ida....	1911	2	3.19	1.286	6.1	....
			4	3.19	3.194	6.4	....
			5	3.19	3.981	5.76	....
Medium clay loam.	Kimberly, Ida....	1912	3	3.71	1.708	5.94	....
			3	3.71	2.070	5.84	....
			6	3.71	3.381	5.70	....

The relation of yield to water used is illustrated by the preceding results of experiments:

The results obtained show that on gravelly soil a much larger quantity of water was used than on more retentive soil. In these experiments the method of irrigation was the same as the customary practice, and consequently the amount used on the gravelly soil includes large losses due to percolation, which can be much reduced by using shorter runs and more frequent light irrigations. The water used on the more retentive soil represents more nearly the proper water requirement. The yield increases with an increase in quantity of water applied, at least up to a certain point, but the increased yield is only slight for a proportionate increase in the water used; in most cases a point is reached where a further addition of water gives practically no increase in yield or even a decrease.

The Experiment Station of the Utah Agricultural College has carried on experiments on small plats near Logan, Utah, to show the relation of yield to water used. The soil of these plats is a deep fertile sand loam with high retentive power for soil moisture. The results are the average of forty-nine trials extending from 1904 to 1911; the soil moisture and rainfall used by the plants in addition to the irrigation water was determined to be 14.91 inches. The yields obtained for different quantities of water are as follows:

YIELD OF ALFALFA FOR DIFFERENT QUANTITIES OF IRRIGATION WATER

(Logan, Utah)

Depth of irrigation water in inches	Yield of alfalfa per acre in tons
10	4.50
15	3.47
20	4.18
25	4.30
30	4.07
50	4.97

While the largest amount of water used produced the greatest yield, the next largest yield was obtained with the least amount of water. The irregularities of these results show that there may be influences, other than that of the total quantity of water applied, and for which there is no apparent explanation, which may affect the yield to a considerable extent.

The above experiments show that:

First.—Large yields of alfalfa, equal to at least two-thirds the maximum yield, may be obtained with small quantities of irrigation water, from 10 to 15 inches for retentive soils where the yearly precipitation is moderate.

Second.—By using intelligently the customary methods of irrigation, eliminating as much as practicable the deep percolation loss, maximum yields or very nearly maximum yields as given below may be obtained for an average retentive deep soil with the following quantities of water; maximum yields of 9 to 10 tons per acre with 30 inches depth of irrigation water, in Sacramento Valley, California, where the average annual rainfall is about 18 inches; maximum yields of 6 to 7 tons per acre with 24 to 30 inches of water in Idaho, where the annual precipitation will average from 10 to 15 inches.

Third.—Very porous gravelly soils, irrigated by the usual method, without special care to prevent deep percolation loss, will require about 2 1/2 times more water than an average retentive clay loam or deep sandy loam. With better irrigation practice to decrease the deep percolation loss, such as shorter runs for the water, larger irrigating heads, more frequent light irrigations, the water requirement of gravelly porous soil can be made to more nearly approach that of more retentive soils.

WATER REQUIREMENTS OF CEREALS FOR MAXIMUM YIELDS

As compared to alfalfa, the water requirement of cereals is much less, the growing period is shorter, the depth of roots is less; for these reasons the water requirement of cereals is influenced to a much greater extent by the extent of the precipitation, especially during the growing period, by the treatment and condition of the soil during the preceding season, and by the time of application of the irrigation water.

At the University Farm at Davis, California, a green manured plot of barley gave a yield in 1911 of 3,740 pounds of hay and 2,146 pounds of grain for 6 inches depth of irrigation water when the seasonal precipitation was 23.18 in.; in 1912 the yield of hay was 3,780 pounds and of grain 1,950 pounds for 17.95 inches of irrigation water in two irrigations when the seasonal precipitation was 9.46 inches.

Don H. Bark, as a result of this work on a large number of fields in Idaho, carried on during the seasons of 1910, 1911, 1912, reached the following average values for the water requirement for maximum yield of grain:

WATER REQUIREMENT OF SOILS FOR MAXIMUM YIELD OF GRAIN IN IDAHO

Class of soil	Season	Number of plots	Depth of water applied	Average
Medium clay and sandy loam soil...	1910	39	1.556	
	1911	49	1.172	
	1912	34	1.623	1.45
Porous sandy and gravelly soil......	1910	16	3.093	
	1911	14	3.088	3.09

The average annual precipitation for a number of stations included in the field of investigations ranges from about 10 to

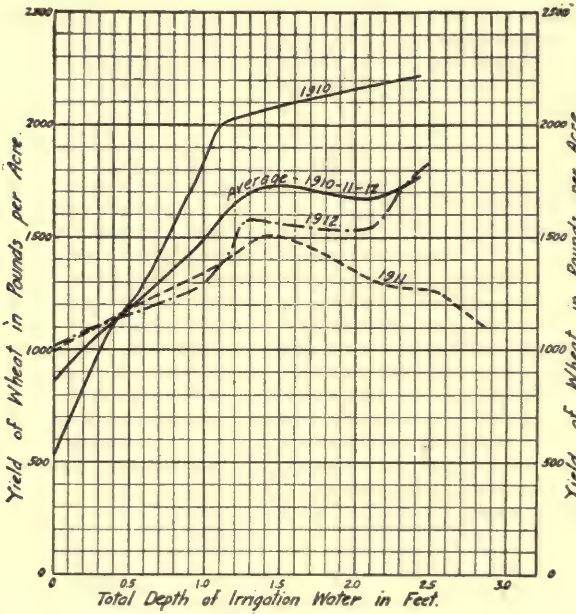

FIG. 16.—Yield per acre of wheat for varying quantities of irrigation water. Gooding Experiment Station, Idaho.

16 inches; the precipitation during the months of April to September, inclusive, ranged from about 1.50 to 3.00 inches for 1910; from 3 to 7 inches for 1911, and from 3 to 8 inches

for 1912. The relation of water used to yield is clearly shown by the curve which is the resultant of the average curves of 1910, 1911, and 1912, obtained by plotting the results for the 21 different subdivisions of the Gooding experiment station planted to wheat, Fig. 16. The soil was a medium clay loam or fine volcanic ash soil, and the precipitation from April to September, inclusive, 3.24 inches. The curve shows a gradual increase in yield with an increase in water applied up to about 1.50 feet, beyond which a further increase in water applied produces a decrease in yield.

The Utah Agricultural College obtained the following average results, from experiments made on a fertile sandy loam near Logan. The results given for wheat are based on 142 trials during an experimental period of 1902 to 1911, those given for oats and barley are based on 29 trials and 10 trials, respectively, for the years 1902, 1903, and 1904 for oats, and 1904, 1905, and 1907 for barley. The soil moisture and rainfall stored in the soil averaged 13.74 inches for the wheat and 9.66 inches for the barley and oats.

Yield per Acre of Cereals for Varying Quantities of Water
(Logan, Utah)

Irrigation water, inches	Yield of grain in bushels per acre		
	Wheat	Barley	Oats
5.00	37.81	.....	62.28
7.50	41.54	68.76	.....
10.00	43.53	.....	54.76
15.00	45.71	67.66	71.54
20.00	.....	.....	80.70
25.00	46.46	66.15	.....
35.00	48.55	.....	.....
39.50	.....	62.59	.....
45.00	.....	.....	79.06
50.00	49.38	.....	.....

The greatest yield of barley was obtained with 7.50 inches of water, of oats with 20 inches, and of wheat with 50, and nearly maximum yields of wheat with 15 inches. These results, with those by Don H. Bark, seem to place the water requirement of cereals for maximum yield per acre at about 18 acre inches per acre, for an average retentive soil.

WATER REQUIREMENT OF POTATOES FOR MAXIMUM YIELD

Don H. Bark obtained the following results at the Gooding Experiment Station for a clay loam soil:

YIELD PER ACRE OF POTATOES FOR VARYING QUANTITIES OF WATER
(Gooding Experiment Station, Idaho)

Year	Precipitation April–Sept., inches	No. of irrigations	Irrigation water in feet	Yield (tons per acre)		
				Total	Per cent. marketable	Marketable
1910	1.85	3	0.876	3.15	68.5	2.16
1910	1.85	5	1.496	5.97	75.0	4.48
1910	1.85	6	2.046	6.47	61.0	3.94
1911	3.98	1	0.539	3.67	52.4	1.92
1911	3.98	5	2.208	8.37	84.6	7.10
1911	3.98	5	3.644	8.38	79.2	6.63
1912	3.47	2	0.541	6.07	78.2	4.75
1912	3.47	5	1.943	9.30	83.1	7.73
1912	3.47	7	2.516	8.34	81.5	6.80

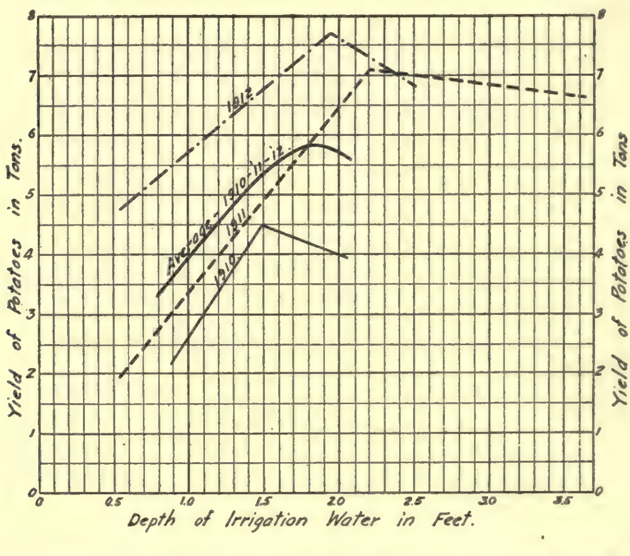

FIG. 17.—Yield per acre of potatoes for varying quantities of irrigation water. Gooding Experiment Station, Idaho.

For all 3 years the greatest quantity of water did not produce the largest per acre yield. The curve which represents the average of the yield and water curves of 1910, 1911, 1912, indicates that

the water requirement for maximum yield per acre is about 2 acre feet per acre (Fig. 17).

Experiments made by the Agricultural College of Utah on the relation of yield to quantity of water used gave the following results:

YIELD OF POTATOES FOR VARYING QUANTITIES OF WATER
(Utah)

Locality and soil	Depth of water applied in inches	Yield in bushels per acre
Salt Lake County:	7 1/2	210
Black loam soil underlaid with clay soil.	10	217
	11 3/4	258
	16 1/4	270
	20 1/2	265
Morgan County:		
Medium clay loam soil.	17 3/4	257
	19 1/4	325
	19 3/4	227
	21 1/2	250
	25 1/2	282
	26	205
Experiment Station Plat:		
Fertile sandy loam.	9	124
	15	217
	20	446
	27	362
	40	523

The average results obtained by experiments carried on during the years of 1904 to 1911 by the Utah Station on a fertile, fine, sandy loam soil are reproduced in the following table:

YIELD OF POTATOES FOR VARYING QUANTITIES OF WATER
(Fine sandy loam soil, Logan, Utah)

Depth of irrigation water, inches	Yield in bushels per acre	
	Total yield	Yield of marketable potatoes
5.00	154	115
7.50	182	136
10.00	195	152
15.00	227	186
20.00	267	215
30.00	244	195
45.00	253	201
60.00	304	234

The yield was greatest with 60 inches of water; but less than 10 per cent. greater than the next largest yield which was obtained with 20 inches. The result of this work carried on at Utah and Idaho indicates that 18 to 24 inches of irrigation water may be considered as the water requirement for maximum yield of potatoes.

WATER REQUIREMENT FOR MAXIMUM YIELDS OF SUGAR BEETS

The Utah Station has obtained the following results as the average of 152 single trials extending over the years of 1904 to 1911. The soil was a fertile, deep, fine sandy loam. The rainfall retained in the soil and soil moisture was equivalent to 10.25 inches of water.

YIELD OF SUGAR BEETS, FOR VARYING QUANTITIES OF WATER; FINE SANDY LOAM SOIL

(Logan, Utah)

Depth of irrigation, water	Yields in tons per acre
5	13.78
10	18.63
15	19.45
20	21.28
30	20.82
50	24.54

The results are very similar to those obtained for potatoes, also a root crop. The yield was greatest for the largest quantity of water, but the next greatest yield was for 20 inches.

An experiment in Box Elder County, Utah, carried on in 1905 on a rich clay loam soil, gave the results tabulated below:

YIELD OF SUGAR BEETS FOR VARYING QUANTITIES OF WATER

(Box Elder County, Utah)

Irrigation water, inches	Yield in tons per acre
5.82	18.54
6.66	18.42
7.31	24.20
8.66	19.95
12.02 (night irrigation)	21.32
12.05	20.65
13.24	20.95
15.37	20.63

F. W. Roeding of the Irrigation Investigations of the U. S. Department of Agriculture started investigations in 1905 at Rocky Ford and Loveland, Colorado, on the water requirements

of sugar beets. The soil was a deep clay loam Areas of 1/2 to 1 acre each were planted to beets in rows 20 inches apart and thinned to 10 inches. Some of the fields were irrigated by running the water in alternate furrows, while in the others water was run in every furrow. The method of controlling the flow delivered at the head of each furrow was also varied, using in some cases lath boxes or tubes, placed through the ditch bank at the head of each furrow, while in others open cuts were made in the ditch bank at the head of each furrow. These variations in practice were found to produce decided effects.

The average results of 3 years' investigations disregarding the variations in the methods of applying the water, are summarized in the following table:

EFFECT OF NUMBER OF IRRIGATIONS AND QUANTITY OF WATER UPON YIELD AND QUALITY OF BEETS, DISREGARDING METHODS OF APPLYING WATER

(Average of 3 years at Rocky Ford and Loveland)

Number of irrigations	Depth of water applied, feet	Average depth of each irrigation, feet	Yield per acre, tons	Sugar, per cent.	Purity, per cent.
1	0.51	0.51	9.67	14.7	82.7
2	0.83	0.41	10.79	15.7	83.8
3	1.40	0.47	11.78	14.9	82.5
4	1.62	0.41	12.82	14.6	82.7

The greatest tonnage per acre was obtained with the largest amount of water, but the highest sugar and purity percentages were obtained with two irrigations. The effect of climatic variations from year to year is well shown by the yields obtained at Loveland during the season of 1906 when the rainfall was plentiful and well distributed throughout the growing season. The results are given in the following tables:

EFFECT OF NUMBER OF IRRIGATIONS, VOLUME OF WATER, UPON YIELD AND QUALITY OF BEETS, DISREGARDING METHODS OF APPLYING WATER

(For year 1906 at Loveland, Colorado)

Number of irrigations	Depth of water applied, feet	Average depth of each irrigation, feet	Yield per acre, tons	Sugar, per cent.	Purity, per cent.
1	0.46	0.46	17.41	14.1	81.8
2	0.94	0.47	20.38	14.1	82.1
3	1.35	0.45	17.45	14.0	83.2
4	1.69	0.42	17.20	13.2	81.3

Rainfall During Growing Period in 1906

(Loveland, Colorado)

	Inches
April	4.06
May	2.21
June	1.80
July	2.41
August	1.07
September	2.95
	14.50

The effect on the yield of applying the water in alternate furrows and in every furrow is shown by the following results:

Yield of Beets under Alternate and Every-row Irrigation

Method of irrigation	Yield per acre, tons	Depth of water applied, feet	Number of irrigations
Lath boxes every furrow	24.58	0.86	2
Lath boxes alternate furrows	20.46	1.05	2

A greater yield with a smaller quantity of water is obtained by every furrow irrigation.

The effect on the yield produced by the uneven distribution of water applied through open cuts made in the ditch bank as compared to the more even distribution through lath tubes is indicated by the following results:

Effect of Method of Division of Water to Furrows

Method	Depth applied, feet	Average depth per irrigation, feet	Yield per acre, tons
Lath tube through bank	0.67	0.34	14.10
Open cut in bank	0.68	0.34	11.96
Lath tube through bank	1.67	0.42	18.22
Open cut in bank	1.70	0.43	15.00

WATER REQUIREMENT FOR MAXIMUM YIELDS FROM ORCHARDS

Experiments to determine directly the relation between quantity of water applied and yields have not been made, or are not known to the writer. By indirect consideration of soil moisture conditions and duty of water, an estimate of the water requirement will be made under the discussion of the proper time and frequency of irrigation and under the subject of duty of water.

(For list of references, see end of Chapter IV.)

CHAPTER IV

RESULTS OF INVESTIGATIONS AND IRRIGATION PRACTICE REGARDING PROPER TIME TO IRRIGATE—FREQUENCY OF IRRIGATIONS FOR DIFFERENT CROPS—IRRIGATION SEASON

Irrigation water is usually applied during a part of the year which corresponds in general with the period of plant growth. The beginning of the irrigation season will depend largely on the available water supply, upon the crop, the amount of the seasonal precipitation, the character of the soil, and the climatic conditions, especially the temperature of the soil and water.

Where the water is obtained from a stream which furnishes a supply during only a short period or when it is deficient during all or part of the usual period of plant growth, then the irrigation season may have to be fixed so as to conform with the available stream flow, as stated farther in the discussion of the seasonal duty of water. In this chapter the effect of the available water supply will not be considered.

EFFECT OF CHARACTER OF SOIL AND PRECIPITATION ON BEGINNING OF IRRIGATION SEASON

A sandy loam or clay loam which has a good retentive power for soil moisture will not require early irrigation where the winter and spring precipitation is considerable or when winter irrigation is practised. The Utah Agricultural College found that an irrigated fine sandy loam soil that was comparatively dry in the fall retained in the upper 8 feet of soil 82 per cent. of the winter and spring precipitation, and for a sandy soil 65 per cent. These are the average results of measurements extending over a period of five years. Porous, coarse, sandy or gravelly soil, which has little retentive power, will require early irrigation, and for new crops may require irrigation before planting.

EFFECT OF WATER AND SOIL TEMPERATURE ON IRRIGATION SEASON

The temperature of the water may have considerable effect on the proper time of beginning of the irrigation season. Cold water, if applied in large quantities, will lower the temperature of the soil below that which is best for plant growth (denoted by optimum soil temperature for plant growth). When the soil moisture for plant growth is not lacking, the application of cold irrigation water is a detriment. The range of temperatures during which there is plant growth and the optimum temperatures are indicated by the following tabulated observations:

SOIL TEMPERATURES FOR PLANT GROWTH

Crops	Minimum temperature, Deg. Fahr.	Optimum, Deg. Fahr.	Maximum, Deg. Fahr.	Authority
Mustard and cabbage.	32.0	78.8	98.6	La Terre Arable par J. Dumont
Wheat, barley, oats.	41.0	80.4	120.2	J. Dumont
Wheat	41.0	84.0	108.0	Goodale
Barley	41.0	84.0	100.0	Goodale
Wheat, rye, oats, flax	....	70–79	....	Haberlandt
Corn	49.0	91.0	115.0	Goodale
Corn, sorghum	48.2	91.4	116.6	J. Dumont
Corn	....	95–101	....	Haberlandt
Horsebeans, beans, peas.	46.4	87.8	107.6	J. Dumont
Cucumber, melons	50.8	96.8	113.0	J. Dumont
Pumpkins	....	95–101	....	Haberlandt

Professor Hilgard states that most cultivated plants may be considered as practically inactive between 40° and 45° Fahr.

SOIL MOISTURE CONDITION DURING IRRIGATION SEASON

Throughout the irrigation season the best results would be obtained if the soil moisture percentage would be maintained at that quantity which is best for plant growth, and which is probably variable, depending on the stage of the plant growth. This would require the continuous addition of irrigation water at a rate which would replace the moisture used by plants and lost by evaporation and percolation. In actual practice it would be impracticable to supply this small continuous rate of flow, and the water

is applied at intervals, during which the moisture content of the soil will vary from a maximum immediately after the irrigation water to a minimum just prior to the next irrigation. The moisture content may therefore range on either side of the best moisture content for plant growth from an excessive amount to an amount which may be as low or lower than the wilting point of plants when the time between irrigations is too long. It is important that in no case the irrigation interval be so long that the soil moisture content be decreased so as to approach the wilting coefficient. The need for irrigation and the intelligent control of the soil moisture would best be obtained by soil moisture determinations. Determinations of soil moisture immediately after irrigation and at the end of the irrigation interval just prior to the next irrigation will give the loss in soil moisture, from which may be obtained the equivalent amount of irrigation water in inches used to produce plant growth and lost by evaporation; this would also represent the quantity of water to use at each irrigation without any allowance for percolation loss. The proper moisture content would therefore best be obtained by light irrigations applied frequently; but the soil conditions and practical considerations such as the extra labor required for frequent irrigations modify this theoretical practice.

FREQUENCY OF IRRIGATION

The frequency of irrigation must be largely dependent on the quantity of water which it is practicable to apply with minimum losses of evaporation and deep percolation beyond the feeding zone of plant roots. Light irrigations applied frequently maintain in the surface soil a higher degree of moisture for a longer period than heavy irrigations applied less frequently, and therefore increase the evaporation loss. On the other hand, very heavy irrigations will cause greater percolation losses, especially in porous non-retentive soils. On retentive soils it is practicable to largely eliminate deep percolation losses; but on sandy open soils it is frequently impracticable to apply only the moisture which can be retained by the soil; however, by proper irrigation methods, the deep percolation loss can be much reduced.

The following experiments on common irrigated crops may indicate the proper irrigation practice.

INVESTIGATIONS ON PROPER TIME TO IRRIGATE CROPS AND IRRIGATION PRACTICE

ALFALFA

Alfalfa Investigations.—The investigations made at Utah, Idaho, Montana, and California indicate that for a medium retentive soil 30 inches depth of water properly applied will give maximum or nearly maximum yields per acre. The depth to apply at a single irrigation and the time of the application has been investigated at Davis, Cal., by the Irrigation Investigations of the U. S. Department of Agriculture; in Utah by the Agricultural College; at Idaho by Don H. Bark of the Irrigation Investigations, U. S. Department of Agriculture. At Davis, Cal., the following results were obtained for a deep sandy loam soil:

Effect of Time of Application, and Number of Irrigations on Alfalfa Yield
(Davis, California)

Number of irrigations	Schedule	Total yield per season, tons per acre		
		1910	1911	Average
4	7 1/2 in. irrigation, water applied immediately after cutting.	7.53	9.61	8.57
8	3 3/4 in. irrigation, water applied in two irrigations between cuttings.	8.24	9.91	9.08
4	7 1/2 in. irrigation, water applied just before cuttings.	7.97	8.95	8.46

At Logan, Utah, the effect of the time of application of water was investigated by applying on a deep, fine, sandy loam soil a total depth of 25 inches, in four equal irrigations at different times. The results obtained are tabulated below:

Effect of Time of Application on Alfalfa Yield
(Logan, Utah)

With 25 inches of water in four equal irrigations Time of application	Yield in tons per acre
Irrigated just before cutting first and second crops and 15 days after each cutting	5.099
Irrigated just after cutting first and second crops and 15 days after each cutting.	5.067

Mr. Don H. Bark states that the time of application of water has not seemed to have any material effect upon the yield of alfalfa, provided the ground was kept uniformly moist throughout the season. The results obtained at Davis, Cal., and at Logan, Utah, show that for a fine sandy loam the yield is practically the same for irrigation before and irrigation after each cutting. At Davis, Cal., two irrigations between cuttings gave a slightly greater yield than obtained with a single irrigation between cuttings, when the total depth of water applied is the same. For a less retentive soil the difference in yield would no doubt be greater and in favor of the frequent light application.

Irrigation Practice for Young Alfalfa.—Where the winter and spring precipitation is sufficient, or where winter irrigation has been practised, soils which have good soil moisture retentive power need no irrigation before seeding the first crop, which in most localities generally occurs in the spring months after the danger of killing frosts is passed. Porous soils which have little retentive power for soil moisture usually require irrigation before seeding. After seeding the young alfalfa plants should receive no further irrigation until the plants show the need for water or even not until they show signs of suffering for lack of moisture; this is desirable to develop the root system downward instead of confining it to the surface, as may occur with too early irrigations. The root system can be further strengthened by cutting the young alfalfa when 8 inches high. The first irrigation is followed by other irrigations applied when necessary.

Irrigation Practice for Established Alfalfa Plants.—When the alfalfa has established a well-developed deep root system the common practice on retentive soil is to apply one irrigation either before or after cutting. On gravelly porous soils and on shallow soils, two or even three irrigations for each cutting may be necessary. Irrigation before cutting decreases the evaporation loss of water because of shade made by the plants; it also tends to prevent baking of the soil and permits an earlier irrigation for the last cutting, which is advantageous when the water supply is deficient before the end of the season. The disadvantages of irrigation before cutting are that the plants interfere more or less with the distribution of water, and the soil may require considerable time to dry out sufficiently to permit harvesting.

Dr. Samuel Fortier, Chief of Irrigation Investigations, U. S. Department of Agriculture, gives the following information in Farmers' Bulletin No. 373:

"The general appearance, and more particularly the color of the plant, are the best guides, perhaps, as to when water is needed. When healthy and vigorous, alfalfa is of a light-green color, but when the supply of moisture is insufficient the leaves take on a darker and duller shade of green and begin to droop, and unless water is provided both stems and leaves wither and die. Another test is to remove a handful of soil 6 inches or so beneath the surface and compress it in the hand. If it retains its ball-like shape after the pressure has been removed, and shows the imprints of the fingers, the soil is sufficiently moist, but if it falls apart readily it is too dry. In connection with such tests it is well to bear in mind that they are more or less influenced by both soil and climate. It is therefore necessary to observe the growth of the plant closely on all new alfalfa fields to determine if possible how far such tests may be relied upon, the chief object being to maintain at all times as nearly as practicable the proper amount of moisture in the soil surrounding the roots of the plants to prevent a checking of their growth.

"Alfalfa commonly receives careless treatment at the hands of western irrigators. When water is available and is not needed for other crops, it is usually turned on the alfalfa fields or meadows, whether these need it or not. There is no question that yields of alfalfa might be considerably increased if more care were used in finding out when to apply water. In each kind of soil and under any given set of climatic conditions there is a certain percentage of soil moisture which will give best results. Under the present unskilful practice it is impossible to maintain uniform soil-moisture conditions for any length of time. The soil is apt to receive too much or too little water, or else it is deluged with cold water at a time when it needs only heat and air. The number of irrigations required depends upon the depth and nature of the soil, the depth to ground water, the number of cuttings, and the rainfall, temperature, and wind movement. Other things being equal, more frequent waterings are required in the warm sections of the South than in the cooler portions of the North. The number of irrigations per year for alfalfa ranges from four in Montana and Wyoming to as many as twelve in parts of California and

Arizona. In localities where water is scarce during part of the season the number of waterings as well as the amount used each time depends on the available supply. It is a common practice to apply frequent and heavy irrigations in spring when water is abundant and to water less often and more sparingly when the supply is low."

CEREALS

Cereal Investigations.—Some of the results obtained by investigations made by the Utah Agricultural College on a fine sandy loam soil are reported in the table below:

EFFECT OF THE DISTRIBUTION OF IRRIGATION ON THE YIELD OF WHEAT AND OATS

(Logan, Utah)

Crop	Total depth of irrigation, inches	Number of irrigations	Depth of each irrigation and order	Yield, bushels per acre
Wheat................	10	2	2.5–7.5	44.47
		3	3.33–3.33–3.33	43.75
		2	5.0–5.0	45.71
		2	7.5–2.5	43.04
Wheat................	15	3	3.75–3.75–7.5	47.28
		3	5.0–5.0–5.0	42 48
		2	7.5–7.5	46.58
Oats..................	15	3	5.0–5.0–5.0	80.29
		2	7.5–7.5	72.68

These results do not show any decided effect, but may indicate that in general the best yield will be obtained when the soil is kept moist throughout the growing season, with the last and perhaps heaviest irrigation when the grain comes to a head or soon after. Where the winter precipitation retained by the soil and the spring rains are sufficient to start the grain, the best yield of grain from a single irrigation will be obtained if it is applied late.

Irrigation Practice for Cereals.—The soil should contain sufficient moisture at the time of seeding to germinate the seed and start the plants growing. No irrigation before seeding is required for a retentive soil when the winter and spring rainfall is not too small, or when the soil moisture has been supplied by winter irrigation. Irrigation before seeding is necessary for a soil which is too dry because of

deficient winter precipitation or winter irrigation. Where irrigation before seeding will keep the ground wet too long and delay the seeding, it may be necessary to irrigate immediately after planting. This practice is objectionable for soils that have a tendency to bake; it increases the evaporation loss and requires an earlier second irrigation.

After the plants have germinated, the first irrigation should not be applied until the plants require it, but before the plants begin to suffer for moisture, which for a moderately retentive soil will be 2 or 3 months after seeding when the plants shade the ground and have grown to a height of 6 to 9 inches. A second irrigation is usually necessary when the heads just begin to form, and a third irrigation is often desirable when the heads are filling out. The practice will vary especially with the character of the soil and the time and extent of precipitation; a good retentive deep soil with a moderate winter and spring precipitation may require only one late irrigation when the heads just begin to form; a porous soil may require four light irrigations.

POTATOES AND SUGAR BEETS

Potatoes and Sugar Beets Investigations.—Some of the results obtained by the Utah Agricultural College are tabulated on page 59.

For potatoes on this type of soil it was shown that 20 inches depth of irrigation water will give practically maximum yield. The above table shows that the best distribution of this quantity of water is in six irrigations, averaging about 3 2/3 inches each, although four irrigations each 5 inches deep gave nearly the same result. The extra labor of applying two or more irrigations is not justified by the small extra yield. With 15 inches total quantity of water, about 4 inches at each irrigation seems to give best yields. With sugar beets similar results are obtained. Additional experiments on sugar beets, which in Utah are seeded about the middle of May and harvested about the middle of November, show that most of the water should be applied in July and August with a light irrigation in September. For 20 inches of irrigation water the best yield was obtained with 6.50 inches in July, 10.50 inches in August, and 1.50 in September.

Irrigation Practice for Potatoes and Sugar Beets.—Retentive soil except for late planting is usually sufficiently moist from the winter and spring precipitation to require no irrigation

EFFECT OF THE DISTRIBUTION OF IRRIGATION WATER ON THE YIELD OF MARKETABLE POTATOES AND SUGAR BEETS
(Logan, Utah)

Crop	Total depth of irrigation water, inches	Number of irrigations	Yield
			Bushels per acre
Potatoes..............	5.0	1	123.13
		2	102.19
Potatoes..............	10.0	2	154.60
		3	143.62
		5	130.31
Potatoes..............	15.0	3	170.19
		4	262.20
		5	149.96
Potatoes..............	20.0	4	331.90
		6	353.12
			Tons per acre
Sugar beets............	10.0	2	27.95
	10.0	3	26.85
Sugar beets............	12.5	2	26.05
	12.5	3	27.15
Sugar beets............	15.0	3	25.26
	15.0	4	25.62

before seeding. Dry soil must be irrigated before planting. Planting in dry hot soil, followed immediately by irrigation is not desirable. During the first stages of growth thorough cultivation is more important than irrigation, and no irrigation may be necessary until July. Too early irrigation after planting may compact and bake the soil around the roots. Potato vines are shallow rooted and frequent irrigations, especially early in the season when the water is cold, will retard the growth; for this reason some irrigators prefer to apply the water at night, when the soil and water have had all day to warm up in the sun. The moisture in the soil should be kept fairly uniform until the tubers begin to form, when a heavier irrigation is generally required. The soil should not be allowed to harden around the roots. The last irrigation should be applied before the growth of tuber ceases, in order to give about 1 1/2 months to 2 months for

ripening in dry earth. In localities of severe winter climates, where potatoes are grown as an intercrop between tree rows, late irrigation and cultivation after the first of August will keep the orchard in growing condition too late in the fall and will not give the wood of the trees sufficient time to mature before the first hard frosts, and may cause winter-killing. The number of irrigations will vary from two to four for ordinary sandy loam, and from four to six light irrigations for a porous sandy soil or shallow soil. The need of irrigation may be indicated by the appearance of the plants; dark leaves indicate a lack of moisture, light yellowish green leaves indicate an excess. An examination of the soil where the tubers form is another good indication. A sandy soil is in good condition when a ball of earth squeezed in the hand will retain its shape.

Proper irrigation practice for sugar beets conforms with the practice for potatoes, and the statements made regarding irrigation immediately after seeding and too early irrigation, frequency of irrigation, and time of last irrigation are equally applicable to sugar beets.

ORCHARDS

Investigations and Practice.—The growth and the crop yield of fruit trees require that the proper degree of moisture be maintained in the soil during the period of growth and bearing of the tree. Deciduous trees are deep rooted when the soil conditions are favorable; they require less water than other irrigated crops, and for that reason the need for irrigation is not so apparent. On a deep retentive soil, with an abundant winter and spring precipitation, fair crops can usually be obtained, but while irrigation may not be necessary, it is usually desirable for full-bearing trees. Citrus trees are not as deep rooted as deciduous trees; they are evergreen, and therefore the evaporation from their leaves is continuous and the maximum moisture need for fruit growth is in the fall; for these reasons citrus trees require more irrigation than deciduous trees. Professor Wickson, after a careful consideration of considerable data, makes the following estimates:

"For deciduous fruit trees on deep soils, fairly retentive, 10 inches of irrigation water, applied at the proper time, during 5 months of growth and fruiting, accompanied by good cultivation, is sufficient,

even when the rainfall is only about enough to prevent drying out during the winter.

"For citrus trees 20 inches of irrigation water is usually sufficient. Where the rainfall is considerable and for the more retentive soils, 10 inches applied at the right time may be adequate."

The proper time to irrigate may be indicated by the appearance of the fruits and leaves; but irrigation should not be delayed until signs of suffering are observed. Suffering for lack of moisture is indicated by the leaves being too light in color and small; by short and thin wood growth, by fading and wilting, or by small inferior fruit. The time to irrigate and the quantity of water to apply can best be obtained by determinations of the moisture in the soil where the mass of the roots is confined. After the orchardist has become familiar with his soil and knows the best percentage of moisture for his trees, he may be able to tell readily, by taking a sample of the soil in his hand, whether there is sufficient moisture or not. The minimum and maximum amount of free soil moisture between which the moisture content must be kept has been indicated in preceding pages.

The experiments made by Dr. Loughridge on citrus orchards in Southern California, previously referred to, are of interest in guiding the proper irrigation practice. The orchards were irrigated according to the usual practice by means of furrows, usually four between tree rows; the distribution of the water applied in the soil was shown by percolation diagrams obtained from observations and measurements made in trenches across the furrows and from borings. These investigations showed that 24 hours after running the water in the furrows for the usual length of time, 48 to 76 hours, the moisture travelled very slowly and the soil was not wetted uniformly, the soil directly under the furrows was the wettest, and the moisture spread laterally on each side to a maximum distance of 2 to 3 feet for a sandy loam and heavy loam respectively. The wetted area at each trench varied from a maximum of 100 per cent. to a minimum of 34 per cent. of the entire area down to the maximum depth of percolation. For a sandy loam soil, the maximum depth of water penetration for a short distance at the upper end of the furrows varied from 26 feet to 9 feet, representing a considerable loss by deep percolation; at the extreme lower end surplus water caused deep percolation to a depth of 14 feet and more; in between, the depth of penetration

was in general less than 5 feet and probably averaged about 8 feet for the entire orchard. For heavy loam and clay loam soils of three orchards, the deep percolation at the upper and lower end of the furrows did not exist, and the maximum depth of water penetration ranged from about 3 feet to 5 feet, averaging about 4 feet. The moisture content of the wetted area averaged from about 4.71 per cent. by weight before irrigation to 9.42 per cent. immediately after irrigation for a sandy loam soil, and from 5.69 before irrigation to 10.73 immediately after irrigation for the average of three heavy loam and clay loam soils. The free moisture 6 weeks after irrigation was reduced by soil evaporation and plant transpiraton to about the same or slightly higher percentage than before the preceding irrigation. Based on these figures with irrigation at 6-week intervals, the percentage of free moisture to add to the wetted area at each irrigation would be about 4.71 per cent. for sandy loam soil and 5.04 per cent. for clay loam soil. For a sandy loam soil and clay loam soil weighing respectively 110 pounds and 105 pounds per cubic foot, this is equivalent to 1 inch depth of water to 12 inches depth of soil. But as the wetted soil is only a fraction of the entire soil volume down to the depth of water penetration, averaging about two-thirds or 66 per cent., 1 inch depth of irrigation water is sufficient for 18 inches depth of soil. These results are based on investigations carried on with full-grown orange orchards, in good condition, and represent actual irrigation practice. The maximum depth of root penetration in the sandy loam soil was 6 feet, but the larger part of the root system was confined to the upper 4 feet and in some places to the upper 2 feet. For these average conditions and for a clay loam or fairly retentive soil, where loss of water by deep percolation can be controlled, the proper degree of moisture in 4 feet depth of soil can be maintained for a period of 6 weeks by the application of 2 2/3 inches depth of water. For a sandy soil, the loss of water by deep percolation may be assumed to increase the depth of soil wetted to an average of 6 feet; this increases the quantity of water used 50 per cent. and gives 4 inches for a single irrigation. These estimates must be increased by the evaporation loss during the period of application of water, which was shown to be about 1/3 inch in depth; this correction gives 3 inches and 4 1/3 inches respectively, for a clay loam and sandy soil, as the depth of

water to be applied for each single irrigation at intervals of 6 weeks during the irrigation season.

Deciduous trees are generally deep rooted, and the moisture content in the feeding zone of the plant roots will not be decreased as quickly as for orange trees. The above figures are based on actual practice with orange orchards, which require about twice as much water as orchards of deciduous trees. However, the evaporation loss from the soil would be about the same for all trees; therefore deciduous trees will probably require about two-thirds as much as citrus trees. About 2 inches of irrigation for clay loam soil and 3 inches for sandy loam soil, applied at intervals of 45 days during the irrigation season, would be sufficient where the winter and spring precipitation are moderate. That this amount is sufficient, for a young apple orchard at least, is indicated by the following case in Idaho described by Don H. Bark, in charge of Irrigation Investigations for the U. S. Department of Agriculture. The orchard is a 5-year-old orchard located at Twin Falls, where the annual precipitation varies from about 8 to 18 inches. During the growing season of 1910 the rainfall was 1 1/2 inches and the depth of irrigation water applied was about 7 1/4 inches. The soil was kept well mulched by frequent cultivations and the moisture at the end of the season in the fall was fully as high as at the beginning of the season. This one case is not conclusive, but it shows the possibilities of small quantities of water carefully used. Other examples of the careful use of water for the irrigation of deciduous fruits are the following for the State of Washington, given by Mr. S. O Jayne, Irrigation Manager U. S. Department of Agriculture:

"The water on a 20-acre apple orchard at Wenatchee was measured during the season of 1908, showing that a depth of 23.04 inches was applied between May 13 and September 23. On the same orchard in 1910, 27 inches of water were used; the first irrigation was May 30 and the last September 12. The trees were 7 years old in 1908 and bore very heavy crops in 1909 and 1910. The orchard is one of the best cared for as well as one of the best producers of the Wenatchee district and the irrigation was done with more than ordinary care and intelligence; but the soil texture is rather coarse and the water-holding capacity low, thus favorable to large percolation losses in the subsoil. Undoubtedly a considerable saving in water would have been possible had the furrows used been only 330 feet long instead of twice that length."

"Another Wenatchee orchard of 50 acres, including apples, peaches and other fruits, used 16 inches in 1908 and 17.5 inches in 1910. The soil here was somewhat heavier than in the former case, but the furrows used were twice as long and besides the run-off was considerable. Part of the orchard, however, was not in bearing and none of it so uniformly good as the other example cited. The annual precipitation at Wenatchee is about 6 to 8 inches and comes late in the fall, winter and early spring."

"The records of one of the Spokane valley companies show that on that system a depth of 14.7 inches was applied in 1905, 19.2 inches in 1906, 22.8 inches in 1907, and 17 inches in 1910. The annual precipitation at Spokane is about 18 inches, of which less than a fourth occurs during the irrigation season."

In the Bitter Root Valley of Montana, measurements were made on a 40-acre tract of orchard trees. The top soil was a vegetable loam underlaid by a subsoil of gravel and small cobbles. In 1900 the 5-year-old orchard was irrigated in April, June, July and August. The total depth applied in the four irrigations was about 18 inches and the rainfall during the irrigation season was 1 1/2 inches. In 1901 the 6-year-old orchard received four irrigations and the total depth applied was 18.7 inches; the rainfall during the season was 5.9 inches. In 1902 the orchard received 21 inches of irrigation water and the rainfall for the season was 8 inches.

These measurements and others made by the U. S. Department of Agriculture are assembled in the following table.

Net Duty of Water for Orchards

Locality	Acreage	Year	Duty of water, in acre-feet per acre	Remarks
Wenatchee, Wash.	20	1908	1.92	Coarse soil
Wenatchee, Wash.	20	1910	2.25	Coarse soil
Wenatchee, Wash.	50	1908	1.33	Medium soil
Wenatchee, Wash.	50	1910	1.45	Medium soil
Spokane Valley System, Wash.	....	1905	1.23	....
Spokane Valley System, Wash.	....	1906	1.60	....
Spokane Valley System, Wash.	....	1907	1.90	....
Spokane Valley System, Wash.	....	1910	1.42	....
Boise Valley, Idaho	1 farm	.....	1.48	....
Bitter Root Valley, Mont.	40	1900	1.50	Vegetable loam
Bitter Root Valley, Mont.	40	1901	1.56	underlaid with
Bitter Root Valley, Mont.	40	1902	1.77	subsoil of gravel and small cobbles.
Average			1.62	

It is interesting to notice that the measurements made on citrus orchards showed that the amount of soil moisture supplied to sandy loam soil was practically the same as for heavy loam soil and clay loam. This is probably true of any soil which is sufficiently deep and not underlaid with a very open sandy or gravelly soil, in which case the sandy soil should be irrigated more frequently and less depth of water applied at each irrigation.

NUMBER OF IRRIGATIONS PER SEASON

The number of irrigations will depend on the capacity of soil to retain water. The orchardist should be guided mainly by the examination of his soil and should try to keep the moisture content within the limits stated above; that is, the free moisture should be between 5 and 10 per cent. of the weight of the soil. For an open soil, well drained, or for a shallow soil, light irrigations applied frequently are best; for a deep retentive soil three to four irrigations 4 or 6 inches deep are ample. The practice in some of the fruit-growing districts of Washington, Idaho, Montana, and Colorado is described by Professor Fortier in U. S. Department of Agriculture, Farmers' Bulletin 404, on Irrigation of Orchards, as follows;

"In the Yakima and Wenatchee fruit-growing districts of Washington, the first irrigation is usually given in April or early in May. Then follow three to four waterings at intervals of 20 to 30 days. At Montrose, Colo., water is used three to five times in a season. At Payette, Idaho, the same number of irrigations is applied, beginning about June 1 in ordinary seasons and repeating the operation at the end of 30-day intervals. As a rule, the orchards at Lewiston, Idaho, are watered three times, beginning about June 15. From two to four waterings suffice for fruit trees in the vicinity of Boulder, Colo. The last irrigation is given on or before September 5, so that the new wood may have a chance to mature before heavy freezes occur. Trees in bearing are, as a rule, irrigated about July 15, August 10, and August 20, of each year."

R. W. Fisher, horticulturist for the Montana Agricultural College, states the following:

"As a general rule, young trees need not be irrigated more than once or twice during a season. Old bearing trees will require from two to four irrigations. Young trees are irrigated about June 15 and possibly July 15. In connection it may be added that the mean annual rainfall

is about 12 to 15 inches, about half of which comes in the months of May, June, July and August."

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CHAPTER V

DUTY OF WATER

DEFINITION

The term "duty of water" as commonly used expresses the relation between the area of land served and the quantity of water used. It is further qualified by using the expressions gross duty, duty measured at heads of laterals, and net duty.

The gross duty of water represents the relation between the quantity of water diverted from the source of supply and the total area of land irrigated by the canal system. It is obtained from measurements of the flow taken at the head of the system and includes besides the quantity of water applied to the land, all losses and waste in conveyance. The area is usually that actually irrigated by the system, but in some cases the area as stated is the total area included in the system which it is possible to irrigate.

The duty of water measured at the head of the laterals is higher than the gross duty because the losses obtained from the head of the main canal to the heads of laterals are not included.

The net duty of water represents the water delivered to the land as obtained by measurements of the water at the margin of the field. It includes besides the volume of water used by the plants, the losses by evaporation, percolation, and waste occurring on the field, which can be controlled to a large extent by a skilful irrigator.

The duty of water is spoken of as high when the area irrigated by a certain volume of water is comparatively large, and as low when the area is comparatively small. The difference between the gross duty and net duty represents the losses and waste in conveyance, and is a measure of the efficiency of the main canal and distributaries. A knowledge of the gross duty is necessary for the engineer to plan the irrigation system in making allowances for the conveyance losses.

The net duty must be distinguished from the correct water

requirement for maximum per acre yield and from the water requirement for maximum economical yield from a limited water supply. The correct water requirement for maximum per acre yield is that quantity of water which is necessary to produce maximum yield per acre when the losses of water by percolation, evaporation, and waste, which can be controlled by practicable skilful methods of irrigation and cultivation, have been eliminated. The water requirement for maximum economical yield from a limited water supply is that quantity of water which correctly used will give the maximum total net returns from a limited water supply, and is dependent on the value of the water, the value of the land, the cost of irrigating, the cost of producing the crop, and the value of the crop. The net duty merely represents the volume of water which is used according to the available water supply, the judgment and skill of the irrigator. Where water is cheap and abundant throughout the irrigation season, the net duty will often exceed the water requirement for maximum per acre yield, because the consequent low price does not enforce careful irrigation and cultivation methods. Where water is scarce and therefore valuable, which is the usual case for a great part of the arid region, the net duty will approach the correct water requirement for maximum total economic yield.

UNITS OF MEASUREMENT OF WATER

In order to express the duty of water, a knowledge of the units of measurement of irrigation water is necessary.

The units of measurement may be divided into two classes: First, those expressing a definite volume of water and generally used to state quantities of water at rest. Second, those expressing a rate of flow or discharge.

The units of volume of water are the gallon, the cubic foot, the acre-inch and the acre-foot. The gallon and the cubic foot may be used for comparatively small volumes of water, and while commonly used as the units of measurement of domestic water, they are not often used for irrigation water. The larger unit, the acre-foot, is the best for expressing large volumes of water; it is the unit most commonly used to state the volume of water in storage reservoirs and for some purposes is the best unit to use in stating the duty of water or the volume of water applied to the land. It represents a volume of water equivalent to a depth of water of 1

foot on an area of 1 acre and is equal to 43,560 cubic feet. The acre-inch is equal to 1/12 of an acre-foot, or equivalent to 1 inch depth of water on an area of 1 acre.

The units of rate of flow of water commonly used are the cubic foot per second and the miner's inch. A term commonly used in expressing the volume of water delivered to or used by the irrigator is the irrigation stream or head of water; this term is not, however, a unit of measurement because the size of stream delivered to the irrigator will vary largely with the method of applying the water on the land and with local practice. It may range from a few miner's inches or a fraction of a cubic foot per second where furrow irrigation is practised to 15 or 20 cubic feet per second where the irrigation method is by flooding in checks, as used in the Sacramento and San Joaquin valleys in California and in some sections of Arizona.

The cubic foot per second, commonly abbreviated to second-foot and in India to cu-sec, is a rate of flow which produces a cubic foot of water each second. It may be defined as a volume of 1 cubic foot of water moving at the rate of 1 lineal foot per second; for instance, a flume 12 inches wide, carrying a depth of water of 12 inches and placed on such a grade as to give a velocity to the water of 1 lineal foot each second, produces a flow of 1 cubic foot per second. In any case the cross sectional area in square feet multiplied by the velocity in feet per second will give the discharge in cubic feet per second.

The miner's inch is usually defined as the quantity of water which discharges freely into the air through a 1 square inch opening when the water stands at a certain constant height above the center of the opening. The number of miner's inches is equal to the area of the orifice in square inches. The value of the miner's inch is controlled by the height of the water level above the center of the opening; but it is also more or less dependent on the shape of the orifice and certain elements which affect the flow of water through orifices. The unit is generally associated with a certain method of measuring water, and unless the factors controlling the method of measurement are correctly followed it is liable to give variable results. In some states the value of the unit or the conditions controlling the method of measurement are defined by law; but the value adopted by custom is sometimes different from that defined by law or else the conditions prescribed

by law are incomplete and do not fix the correct value. This is illustrated by the following cases:

In California the miner's inch as defined by statutes of 1901 is equal to 1 1/2 cubic feet of water per minute; this makes a flow of 40 miner's inches equal to 1 cubic foot per second and gives a pressure head on the center of the opening of 6 inches (approximately). This value of the miner's inch is not, however, generally used in California; many of the irrigation companies use a 4-inch pressure on the center of the opening, which makes the flow of 50 miner's inches equal to 1 cubic foot per second. The height of the opening is not prescribed by law and therefore varies in different sections; for instance, on some systems the height is 2 inches and the length is adjustable; on a number of systems in southern California the height is 5 inches and the water level on the upstream side of the orifice is maintained 1 1/2 inches above the top edge of the orifice, which gives a 4-inch pressure head on the center of the orifice. Variations in the height of the opening affect the value of the miner's inch unit only to a small extent, provided the pressure on the center of the opening is the same. Variations in the thickness of the orifice board may affect the value of the miner's inch.

In Colorado the value of the miner's inch is defined by the laws of 1868 as the flow through an inch orifice under a 5-inch pressure measured from the top of the orifice, and the prescribed height of the orifice is 6 inches except for flows under 12 miner's inches, when the orifice may be square. For flows above 12 inches this gives a pressure on the center of the opening of 8 inches, and for flows under 12 miner's inches the pressure varies from 6.73 inches for a square opening of 12 square inches to 5.5 inches for a square opening of 1 square inch. As a result, the value of the miner's inch varies from about 35 miner's inches to 1 cubic foot per second for an 8-inch head to about 43 miner's inches to 1 cubic foot per second for a 5.5-inch head, but the commonly accepted equivalent is 38.4 miner's inches to 1 cubic foot per second.

In British Columbia the legal value of the miner's inch is the flow through an orifice 2 inches high by 1/2 inch wide, made in a 2-inch plank, the head on the top of the opening being 7 inches; this gives a pressure head on the center of the opening of 8 inches. As defined by law, 35.7 miner's inches are equivalent to 1 cubic foot per second.

In Arizona, Montana, as defined by statutes, and in Oregon as fixed by court decisions, 40 miner's inches are equal to 1 cubic foot per second; this value requires a 6-inch pressure head on the center of the opening.

In Idaho, Nebraska, Nevada, New Mexico, North Dakota, South Dakota and Utah as defined by statutes, 50 miner's inches are equal to 1 cubic foot per second; this value requires a 4-inch pressure head on the center of the opening.

On account of the variations of the value of the miner's inch, not only in different states, but also in different sections of the same state and also because of variations produced by different conditions of measurement, the miner's inch is being largely replaced by the cubic foot per second as the standard unit of measurement. It is the statutory standard in at least the following states:. Colorado, Montana, Nebraska, Nevada, New Mexico, Idaho, North Dakota, Oklahoma, South Dakota, Utah, Washington, Wyoming.

Although the miner's inch as a unit of measurement is open to the objections stated above and also to the term being sometimes confused with the cross sectional area in square inches of a channel, flume or pipe, it has certain advantages which will keep it in use for a long time to come. The main advantage is that for small flows the irrigator has a better understanding of its amount when stated in miner's inches. As a method of measurement it has some advantages which will be explained in the discussion of measurement of water and measuring devices.

RELATION BETWEEN UNITS OF MEASUREMENT OF RATE OF FLOW AND UNITS OF MEASUREMENT OF VOLUME

The cubic foot per second or second-foot and the miner's inch indicate only a rate of flow, and to specify a fixed volume of water it is necessary to state the time or duration of flow. For instance, a continuous flow of 1 cubic foot per second will give in one 24-hour day as many cubic feet as there are seconds in that time or 86,400 cubic feet, which is equal to 1.983 acre-feet. For all practical purposes it is sufficiently accurate to assume that a flow of 1 cubic foot per second will produce 2 acre-feet of water in 24 hours, or 1 acre-inch per hour. To convert measurement from one unit into another the following equivalents are useful:

1 cubic foot = 7.50 gallons (7.48).

1 acre-foot = 43,560 cubic feet = 323,136 gallons.

1 second-foot = 7.50 gallons per second = 450 gallons per minute.

1 second-foot in 24 hours gives nearly 2 acre-feet (1.983).

1 second-foot in 1 hour gives nearly 1 acre-inch.

1 second-foot is equivalent to 40 miner's inches controlled by a 6-inch pressure head.

1 second-foot is equivalent to 50 miner's inches controlled by a 4-inch pressure head.

When 1 miner's inch is equivalent to 1/40 of a second-foot, it will give 11.25 gallons per minute, or nearly 6/10 of an acre-inch, in 24 hours, or 17.37 acre-inches in a month of 30 days.

When 1 miner's inch is equivalent to 1/50 of a second-foot, it will give 9 gallons per minute, or nearly 1/2 of an acre-inch in 24 hours (48/100), or 14 acre-inches in a month of 30 days.

METHODS OF EXPRESSING THE DUTY OF WATER

The duty of water may be stated in two ways:

First.—In number of acres irrigated by a flow of water, usually 1 cubic foot per second or 1 miner's inch, for a stated period of time during the irrigation season.

Second.—In number of acre-feet or acre-inches per acre, which is equivalent to stating the depth of water applied on the land in feet or in inches.

In the first form of expression the time must be specified in order to define a given volume of water. In general it is not a constant value throughout the irrigation season, but varies with the needs and demands on the water supply. It is the form of expression best adapted when the volume of water is stated as a rate of flow; such as when considering the discharge or carrying capacity of canals.

The second form of expression avoids any misunderstanding regarding the volume of water applied. One form of expression can be easily converted into the other by the simple relations previously given.

PRINCIPAL FACTORS AFFECTING GROSS AND NET DUTY

The gross duty is dependent on the net duty and on the conveyance losses. The factors which have more or less effect on the net duty are:

First.—The kind of crops and diversification of crops. It is known that some crops require more water than others; alfalfa

requires more water than deciduous trees; young orchards less than full-bearing orchards. The growing of a single kind of crop will create a comparatively short period of maximum demand for water, which will give a low duty for this period; while the growing of a variety of crops which have different water requirements and different periods of maximum demand will create a more constant demand and increase the duty.

Second.—The preparation of the land, method of application of the water and skill of the irrigator. Poor preparation of the land will cause water to accumulate in the swales, and uniform distribution of water is not obtained. Irrigation through furrows which are too long, or by flooding over too great a distance when the irrigating head is too small, causes a large excess of water at the upper end, which is lost by deep percolation. The practice of rotation, which permits the use of large irrigating heads for short periods, will decrease percolation losses and increase the duty. Careless irrigation will often produce an accumulation and waste of water at the lower end of fields or furrows. In furrow irrigation, unless care is taken in the division of water between furrows, there will be unequal distribution. Deep furrows expose less water and wet soil to the air and decrease the evaporation loss.

Third.—The time and frequency of cultivation. Thorough cultivation as early as possible after irrigation decreases evaporation losses.

Fourth.—Number of seasons irrigation is practised. In all irrigated districts it has been the experience that irrigation causes a rise of the water-table. If this rise is too great, it may submerge the roots and waterlog the soil, but if the water-table rises only to a depth where the soil water can be drawn by capillarity to the roots, this will lessen materially the necessary amount of irrigation water.

Fifth.—Climate. Precipitation, temperature, humidity in the air, wind movement—all have some effect. The rainfall and its distribution are important. Abundant rainfall or snow in the winter will be partly stored in the soil and is available to deep-rooted plants during the growing season, thus decreasing the necessity for irrigation. On the other hand, light showers in the summer may do more harm than good by destroying the soil mulch and increasing soil evaporation. An increase in temperature and in wind movement will increase the soil evaporation.

Sixth.—The length of the irrigation season. Where the irrigation season is long, because of climatic conditions, the growing season is longer and the necessity for irrigation water is greater.

Seventh.—Character of soil and subsoil drainage. A sandy soil underlaid with a porous subsoil which drains readily will take care of large volumes of water without waterlogging and encourages waste.

Eighth.—The value of the water, method of payment for water, judgment and knowledge of the irrigator. A high cost of water leads to higher duty. When water is sold on flat charge per acre of land, independent of the amount of water used, it is human nature for the average irrigator to use all the water he can obtain. On the other hand, when the price for water is based on the quantity actually used, careful irrigation practice prevails, resulting in a high duty. This factor, combined with the judgment of the irrigator, may have more effect on the value of the duty of water than all the other factors combined.

VALUES OF THE DUTY OF WATER

Because of all the factors on which the duty of water depends, there is a great difference in the value of the duty of water obtained in different localities, or even in localities of similar climate, soil and crop conditions, but under different methods of payment for water and different values of water.

Measurements of the duty of water in the arid states of the United States are very numerous. These measurements have been largely made, since about 1898, by the Irrigation Investigations of the U. S. Department of Agriculture, usually in coöperation with the State Governments. A large part of these are assembled in a review of 10 years of irrigation investigations, beginning 1898, by R. P. Teele. More recently the U. S. Reclamation Service has furnished valuable information on the duty obtained on their projects.

VALUES OF THE GROSS DUTY

The duty of water measurements made by the Irrigation Investigations extend mostly from the year 1899 to 1904, inclusive. A large part of these measurements are assembled by R. P. Teele in the following table to represent general practice in the localities mentioned.

GROSS DUTY OF WATER FOR PERIOD EXTENDING FROM 1899 TO 1912 INCLUSIVE, BASED ON MEASUREMENTS BY THE IRRIGATION INVESTIGATIONS OF THE U. S. DEPT. OF AGRICULTURE

Stream	Canal system	Years of measurements	Approximate area irrigated, acres	Water diverted per acre, average, acre-feet
Arizona: Salt River.......	Average of several...	1899 to 1901	113,000	3.42
	Mesa.............	1896 to 1901	60,000	4.47
	Tempe............	1896 to 1901	30,000	3.96
California:				
Santa Ana.............	Gage.............	1899, 1900, 1901	7,000	2.16
Santa Clara...........	Average of several...	1904	5,160	2.00
Tule..................	Average of several...	1901	5,000	4.94
Tuolumne.............	Modesto...........	1904	7,000	13.18
Tuolumne.............	Turlock...........	1904	20,000	8.34
Cache Creek...........	Moore.............	1906	7,000	3.15
Colorado:				
Arkansas..............	Amity.............	1899	16,000	4.92
Arkansas..............	Lake..............	1901	15,000	2.58
Grand.................	Grand Valley.......	1901	22,000	4.11
Cache la Poudre........	New Cache la Poudre	1903	30,000	2.21
Big Thompson.........	Average of two.....	1903	32,000	1.80
St. Vrain..............	Supply.............	1903	7,000	1.79
Clear Creek...........	Average of three.....	1903	53,000	1.37
South Platte...........	Average of several...	1903	67,000	2.90
Idaho:				
Boise River............	Average of several...	1911	44,000	4.53
Boise River............	Average of several...	1912	48,500	5.99
Boise River............	Ridenbaugh Canal..	1901	4,714	4.80
Montana:				
Gallatin...............	Average of several...	1899 to 1903	8,000	3.94
Yellowstone...........	Big Ditch..........	1899 to 1903	25,000	3.08
Bitter Root...........	Average of several...	1899 to 1903	20,000	4.69
Nevada: Truckee.........	Orr Ditch..........	1900	6,000	7.08
Nebraska: North Platte...	Average of several...	1899, 1903	80,000	4.00
New Mexico: Pecos.......	Pecos..............	1899, 1900, 1901	8,500	7.90
Utah:				
Big Cottonwood.........	Average of several...	1899, 1900	8,000	4.13
Logan................	Average of two.....	1899, 1900	6,000	4.08
Bear River............	Bear River.........	1901	17,000	4.84
		1905	34,700	3.50
Washington:				
Naches................	Average of several...	1904	15,000	4.86
Yakima...............	Average of several...	1899 to 1904	50,000	5.70
Wyoming:				
Laramie...............	Canal No. 2........	1899, 1900	6,500	3.72
Deer Creek............	Average of several...	1903	....	10.40
Horseshoe.............	Average of several...	1903	....	9.75

Some of the general conditions, which have a large influence on the duty of water, are mentioned by R. P. Teele. The lower duties of water obtained on the Modesto and Turlock systems in California, on the Amity and Lake system in Colorado, on the Pecos system in New Mexico, on the Bear River system in Utah, and on the Yakima system in Washington are due to the canal systems being in the early stages of development with the land in rather unsettled condition. The low duty of water for the Orr Ditch in Nevada represented average practice on pasture lands in that State, where irrigation methods are crude. The low duty for canal systems supplied from Deer and Horseshoe Creeks in Wyoming is due to crude and very wasteful methods of irrigation on pasture land or hay meadows. The low duty for the Grand Valley system in Colorado results from an abundant water supply. The higher duty obtained on the other systems are for more settled conditions, and represents about what is required for a canal system under present practice. A greater future demand of water will in many cases produce a higher duty. The Gage Canal system in Southern California irrigates largely citrus land and consists of a concrete-lined main canal and distributing pipes. The duty therefore very nearly represents the net duty for citrus orchards. The average of all the measurements made by the Irrigation Investigations for the period from 1899 to 1904, inclusive, gives a gross duty of 5.13 acre-feet per acre. The lower duty for a new canal system results from the greater seepage losses of new canals, the greater water requirement of new arid lands, the more plentiful water supply, because only a part of the land is irrigated, and the inexperience and lack of skill of the new irrigator. As the system gets older, less water is used and the gross duty increases up to a time when settled conditions are obtained; the duty will then represent fairly well the water requirement of soil and crops for the customary irrigation practice; a further increase in the duty will be obtained only by an increase in the value of the water, which will justify special improvements to prevent the large conveyance losses and which will produce more economical irrigation methods. The increase in gross duty with the ageing of the system is shown by the following measurements:

Gross Duty of Water under Sunnyside Canal, Washington

Year	Area irrigated, acres	Quantity of water diverted, acre-feet per acre
1898	6,883	11.4
1899	8,497	10.6
1900	10,947	10.2
1901	14,964	9.6
1902	18,870	9.1
1904	32,000	6.0
1906	32,000	6.5
1909	47,000	4.1
1910	51,000	5.27
1911	58,973	4.97

The lower duties of 1910 and 1911 as compared to that of 1909 are due to greater wastes of water through the wasteways, in the regulation and operation of the system. When this waste is not included in the gross duty, the respective values for 1909, 1910, and 1911 are 3.93, 4.56, and 4.03. The table shows that after 11 years of operation the amount of water diverted per acre was about 2¾ times less than the first year.

A similar increase in the duty is shown on the Modesto and Turlock systems in California.

Gross Duty of Water for Modesto and Turlock Systems, California

Year	Area irrigated by both systems	Gross duty, acre-feet per acre
1904	27,000	9.60
1906	45,272	6.84
1907	61,823	5.62
1909	75,036	5.20
1911	106,062	4.58

On the seventh year of operation of these two systems the amount of water diverted per acre was a little less than one-half the amount diverted the first year.

DUTY OF WATER MEASURED AT THE HEADS OF LATERALS

The duty of water measured at the heads of laterals will be higher than the gross duty obtained from measurements at the

head of the main canals by an amount equal to the conveyance losses and regulation waste occurring between the point of diversion and the heads of laterals, which will depend on the length of main canal from the point of diversion to the head of the distributing lateral. On systems where the diversion main canal is short and the waste in operation is small, the difference will be smaller than for long diversion canals. The value of the duty of water at the heads of laterals and its relation to the gross duty is illustrated by the following measurements made by the Irrigation Investigations of the U. S. Department of Agriculture.

RELATION BETWEEN GROSS DUTY AND DUTY OF WATER MEASURED AT THE HEADS OF LATERALS

(Measurements made by Irrigation Investigations, U. S. Department of Agriculture)

Canal	Stream	Year	Gross duty, acre-feet per acre	Duty for laterals, acre-feet per acre	Per cent. of gross duty
Pioneer	Tule River, Cal.	1901	8.01	1.41	18
Amity	Arkansas River, Colo.	1899	4.92	1.82	37
Pecos	Pecos River, New Mex.	1899, 1900, 1901	7.90	3.69	47
Bear River	Bear River, Utah	1901	4.84	1.84	38
Modesto	Tuolumne, Cal.	1904	13.18	5.76	44
Turlock	Tuolumne, Cal.	1904	8.34	7.69	92
Sunnyside	Yakima, Wash.		6.25	4.73	75

The average duty for laterals of these canal systems is 50 per cent. of the gross duty. Eliminating the values for the Pioneer Canal, which are unusual, the average per cent. is 55. These canal systems are mostly new canals, operated a few years only; older systems will give higher percentages.

NET DUTY OF WATER

Single Measurements.—Measurements of the net duty of water made on single farms vary so widely that they are of value only in showing individual practice. Some of the results obtained by the Irrigation Investigations are given in the following table:

Quantity of Water Used per Acre on Individual Farms
(Measurements made by Irrigation Investigations, U. S. Dept. of Agriculture)

State	Farm	Crop	Water used per acre, acre-feet
Arizona	Vance	Alfalfa and barley	1.98
Arizona	Arizona Experiment Station	Mixed	5.70
California	Measured to all consumers under Pioneer ditch.	Mixed	3.19
California	Sprott orchard	Oranges and lemons	1.55
California	Selected farms under Pioneer ditch	Fruits	2.00
California	Pumped water—average for four years on 25 farms—Lindsay Water Development Co.	Fruits	1.32
Idaho	A. F. Long, 1899	Mixed	2.40
Idaho	A. F. Long, 1900	Mixed	3.03
Idaho	Edgar Wilson	Orchard	1.48
Idaho	C. G. Goodwin, 1900	Mixed	3.25
Idaho	C. G. Goodwin, 1901	Mixed	3.32
Idaho	N. C. Purcell, 1900	Timothy and alfalfa	2.43
Nebraska	D. W. Daggett	Mixed	2.47
New Mexico	Average of 70 under Northern Canal, New Mexico	Mixed	2.49
Utah	Cronquist	Mixed	2.59
Washington	Maurice Evans	Mixed	3.58
Washington	Lower Rattlesnake ranch	Mixed	4.60
Washington	Upper Rattlesnake ranch	Alfalfa	3.11
Washington	Jordan orchard	Orchard	6.03
Washington	Dunn hopyard	Hops	3.43
Washington	R. D. Young	Mixed	10.61
Wyoming	Sigman's ranch	Mixed	3.38
Wyoming	Webber's ranch	Mixed	1.92
California Gage canal	N. P. Cayley	Oranges	1.98
California Gage canal	J. D. Carscaden	Oranges	1.20
California Gage canal	Gulick Bros.	Oranges	2.38
California Gage canal	C. C. Quinn	Oranges	1.98
California Gage canal	C. E. Kennedy	Oranges	2.48
Average			3.07

NET DUTY FOR DIFFERENT CROPS

The average net duty of water for the most important crops of the arid region are presented in the table below, which gives the results of the extensive measurements of the Irrigation Investigations of the U. S. Department of Agriculture.

WATER USED ON DIFFERENT CROPS
(Measurements made by Irrigation Investigations, U. S. Dept. of Agriculture)

State	Alfalfa, acre-feet	Wheat, acre-feet	Oats, acre-feet	Barley, acre-feet	Potatoes, acre-feet	Sugar beets, acre-feet
Arizona	....	2.17	....	1.60	2.10	2.50
California	4.50	....	....	....	....	....
Idaho	2.50	1.05	2.33	1.14	....	1.91
Colorado	....	....	....	....	....	2.40
Montana	1.15	1.43	1.74	1.41	....	1.46
Nevada	6.85	9.27	....	....	7.80	....
Utah	2.97	1.48	1.37	....	1.17	2.24
Washington	3.11	....	....	....	....	....
Wyoming	....	....	1.60	....	3.63	....
Average	3.51	3.03	1.51	1.38	3.90	2.10
Average without Nevada	2.65	1.53	....	....	2.31	....

AVERAGE NET DUTY FOR ALL LAND COVERED BY SYSTEM

Measurements which represent the average net duty for the land under one system are of value in showing average practice. The U. S. Reclamation Service has obtained the values tabulated on page 82 for the net duty on some of the projects. The distribution of the crops is given to indicate the effect of the predominant crops.

RELATION BETWEEN NET DUTY AND GROSS DUTY

The ratio of net duty to gross duty gives the per cent. of diverted water delivered to the land and is a measure of the conveyance efficiency of the system, including also the waste or water returned to the river through the wasteways in the regulation of the flow in the canals. Values obtained by the Irrigation Investigations of the U. S. Department of Agriculture and by the Reclamation

NET DUTY OF WATER ON U. S. RECLAMATION SERVICE PROJECTS

State	Project	Net duty in acre-feet per acre		Total acres	Area irrigated in 1911, per cent. in main crops								
		1910	1911		Alfalfa	Cereals: barley, oats, wheat	Corn	Orchards and fruits	Beets	Potatoes	Pasture	Hay, other than alfalfa	Other crops
Arizona	Salt River	......	4.8	150,961	54.6	28.5	......	1.7	1.3	....	8.1	....	5.8
Arizona, Cal.	Yuma	4.3	6.3	8,570	57.2	12.6	6.6	0.9	......	....	14.0	2.6	6.1
California	Orland	3.4	3.9	2,441	89.0	....	......	11.0	......	....		....	......
Colorado	Uncompahgre	2.9	4.7	44,818	44.0	23.8	0.2	14.2	3.1	11.2	0.3	....	3.2
Idaho	Boise	1.7	1.8	40,856	27.5	33.6	0.7	10.8	......	1.1	15.9	8.8	1.6
Idaho	Minidoka	7.3	4.6	55,558	35.3	35.4	1.8	2.7	0.6	2.8	7.1	10.8	3.5
Montana	Flathead	......	2.0	2,370	....	87.5	......	....	......	....	....	....	12.5
Montana	Huntley	2.0	1.9	11,100	24.1	29.6	3.0	....	27.6	1.7	8.0	3.8	2.2
Montana	Milk River	......	1.4	2,070	1.2	56.7	......	....	......	1.4	....	13.8	26.9
Montana	Sun River	2.3	1.7	6,042	11.0	78.5	......	....	0.1	2.3	5.0	1.3	1.8
Montana, North Dak.	Lower Yellowstone	1.4	1.4	12,407	8.6	77.1	1.2	....	......	0.5	0.2	1.3	11.1
Nebraska, Wyoming.	North Platte	3.9	4.7	58,902	45.4	35.1	7.9	....	0.7	5.9	....	....	5.0
Nevada	Truckee Carson	4.7	4.5	30,139	37.6	....	......	0.3	3.6	1.5	35.0	4.8	17.2
New Mexico	Carlsbad	2.4	2.6	13,677	55.2	0.8	10.2	4.0	......	0.1	1.8	0.2	27.7
North Dak.	Buford Trenton Pumping Unit.	1.4	1.3	1,041	11.6	74.4	2.0	....	......	0.8	....	3.8	7.4
North Dak.	Williston Unit	1.7	1.2	3,128	36.9	52.6	0.6	....	......	2.1	....	3.7	4.1
Oregon	Umatilla	10.0	9.7	3,500	52.5	0.4	......	20.7	......	1.3	....	0.7	24.4
Oregon, Cal.	Klamath	0.9	1.2	22,839	24.0	31.2	......	....	......	0.9	31.2	12.0	0.7
South Dak.	Belle Fourche	1.9	1.6	19,786	12.3	60.7	9.6	....	......	1.7	....	....	15.7
Washington	Okanogan	2.1	0.9	7,438	8.5	5.4	8.2	62.3	......	1.8	....	9.8	4.0
Washington	Yakima Sunnyside Unit.	2.8	2.8	53,076	47.2	....	2.8	31.2	......	3.0	2.2	3.8	9.8
Washington	Tieton Unit	......	1.9	8,613	9.6	....	4.4	43.6	......	10.6	1.8	15.3	14.7
Wyoming	Shoshone	2.1	2.2	17,234	50.7	36.1	0.2	0.4	0.1	1.6	9.1	....	1.8

Service on a number of its projects are assembled in the accompanying table:

RELATION BETWEEN NET DUTY AND GROSS DUTY

State	Canal system	Year of measurement	Gross duty, acre-feet diverted per acre	Duty at head of laterals	Net duty, acre-feet, delivered per acre	Ratio, net duty to gross duty in percent.
California......	Gage..............	1899–1901	2.16	....	1.98	92
Idaho..........	Ridenbaugh laterals.	....	4.79	....	2.50	52
Idaho..........	Boise Valley canals, 12,620 acres.	1911	4.25	....	2.01	47
Montana.......	Sun River Project...	1910	7.29	....	2.26	31
Montana.......	Sun River Project...	1911	3.47	....	1.65	48
Oregon.........	Klamath Project....	1911	2.24	1.45	1.25	55
Oregon.........	Umatilla Project....	1910	16.95	....	9.94	59
Oregon.........	Umatilla Project....	1911	15.70	....	9.70	62
Nebraska, Wyo.	North Platte Project	1911	7.35	....	4.70	65
New Mexico....	Carlsbad Project....	1911	5.75	3.12	2.57	45
Washington....	Sunnyside Project...	1901	9.60	....	3.96	41
Washington....	Sunnyside Project...	1909	4.10	3.23	2.79	68
Washington....	Sunnyside Project...	1910	5.27	3.34	2.83	54
Washington....	Sunnyside Project...	1911	4.97	3.36	2.85	58

The high efficiency of the Gage Canal System in southern California is due to the fact that the main canal is lined with about 1 inch thickness of cement mortar for nearly its entire length and the distributaries are pipe lines.

The Umatilla project is in very porous deep sandy soil; the gross duty is based on the volume of water delivered from the storage reservoir into the main canal of the distribution system.

The lower efficiency obtained on the Sunnyside project during 1910 and 1911 is caused by the very large waste at the spillways and probably to the enlarging of the canal system; excluding the waste for the years 1909, 1910, and 1911, the gross duties are respectively 3.93, 4.56, and 4.03, which give ratios of 71, 62, and 71. The measurements on this canal system show the increase in conveyance efficiency with the ageing of the system.

These tabulated values indicate that in a new canal system of unlined earth canals the water delivered to the farms is probably not more than 40 per cent. of the water diverted. For old canals in good condition the efficiency may be increased to 65 or 70 per cent.

The relation between gross duty, regulation waste, conveyance loss (evaporation and seepage) and net duty for a few projects is tabulated below:

REGULATION WASTE, CONVEYANCE LOSS AND NET DUTY IN PER CENT. OF GROSS DUTY

State	Project	Year	Regulation waste	Conveyance loss			Delivered to farms
				In main canals	In laterals	Total	
Montana...	Sun River Project.........	1910	56.0	....	....	13.0	31.0
Montana...	Sun River Project..........	1911	32.4	....	....	20.0	47.6
Montana...	Sun River Project.........	1912	22.6	....	....	20.0	57.3
Idaho......	Minidoka Northside Project	1910	.....	29.0	....	.....	.....
Idaho......	Minidoka Southside Project	1911	.....	47.0	....	.....	.....
Idaho......	Minidoka Northside and Southside Project	1912	13.5	....	....	26.7	59.8
Oregon.....	Klamath Project..........	1911	4.2	30.9	9.8	40.7	55.0
Oregon.....	Klamath Project..........	1912	.....	....	....	36.0	64.0
New Mexico	Carlsbad Project..........	1911	.....	45.0	10.0	55.0	45.0
New Mexico	Carlsbad Project..........	1912	6.5	....	....	48.0	45.5
Nebraska...	North Platte Project......	1911	1.3	24.7	9.9	33.6	65.0
Utah.......	Bear River System........	1905	2.0	....	....	19.0	79.0
Washington	Okanogan System.........	1910	.....	....	....	45.0	.....
Washington	Okanogan System.........	1911	.....	....	....	52.0	.....
Washington	Okanogan System.........	1912	0.6	....	....	47.2	52.2
Washington	Sunnyside System.........	1909	4.2	16.9	10.9	27.8	68.0
Washington	Sunnyside System.........	1910	14.0	22.5	9.5	32.0	54.0
Washington	Sunnyside System.........	1911	18.0	14.0	10.0	24.0	58.0
Washington	Sunnyside System.........	1912	10.6	....	....	26.6	62.8

Seasonal Duty of Water.—The duty of water is not constant throughout the irrigation season; the variations are due to the variable water requirement of crops and to the available stream flow. It has been shown that for most crops it is desirable to keep the moisture content of the soil fairly uniform during the growing season, but different crops have different water requirements and different growing seasons, and the same crop will have periods of maximum and minimum water requirements at different stages of its growth. The combination of different crops will increase the length of the irrigation period and will usually produce a more uniform duty of water throughout the season.

When the available water supply is sufficient throughout the irrigation season, the duty of water will be proportionate to the variations of the water requirements of the crops. When the available water supply is abundant during part of the irrigation season and deficient for the remainder, the duty of water will be adjusted to the water supply and may lead to the growing of crops

whose maximum demand for water will be at a time when the available water supply is greatest. This practice is specially adapted to deep rooted plants and for deep retentive soils; it is well illustrated by the irrigation practice in the Santa Clara Valley of California, where the stream flow is available in the winter and spring months and deficient during the remainder of the the year; the crops are largely deciduous fruit trees, the soil is generally deep and retentive, and winter and spring irrigation is generally practised.

Don H. Bark, in charge of Irrigation Investigations for the U. S. Department of Agriculture, has obtained the following average seasonal net duty of water as a result of his extensive investigations in Idaho during the years 1910, 1911, 1912.

NET SEASONAL DUTY OF WATER IN SOUTHERN IDAHO, MEDIUM CLAY AND SANDY SOIL (1910–1911–1912)

	Average of 122 fields of cereals		Average of 46 fields of alfalfa		Average for equal areas of grain and alfalfa		
	Acre-feet per acre	Per cent. of total	Acre-feet per acre	Per cent. of total	Acre-feet per acre	Per cent. of total	Acres per second foot
April 1–15	0.000	0.00	0.018	0.72	0.009	0.46	3,300
April 16–30	0.000	0.00	0.014	0.56	0.007	0.36	4,250
May	0.114	7.86	0.521	20.90	0.318	16.08	187
June	0.759	52.34	0.490	19.65	0.6245	31.67	95
July	0.524	36.14	0.748	30.00	0.636	32.25	93
Aug	0.053	3.66	0.592	23.75	0.323	16.38	185
Sept. 1–15	0.000	0.00	0.100	4.02	0.050	2.54	595
Sept. 16–30	0.000	0.00	0.010	0.40	0.005	0.25	5,950
	1.45	100.00	2.5	100.00	1.972	100.00	.....

NET SEASONAL DUTY OF WATER IN SOUTHERN IDAHO, POROUS, SANDY AND GRAVELLY SOILS (1910–1911)

	Average of 30 fields of cereals		Average of 17 fields of alfalfa		Average of equal areas of grain and alfalfa		
	Acre-feet per acre	Per cent. of total	Acre-feet per acre	Per cent. of total	Acre-feet per acre	Per cent. of total	Acres per second feet
April 1–15	0.000	0.00	0.00	0.00	....	....	....
April 16–30	0.000	0.00	0.326	4.78	0.163	3.29	1,840
May	0.039	1.26	1.306	19.16	0.672	13.57	88.5
June	1.337	43.27	1.690	24.80	1.514	30.57	39.0
July	1.142	36.96	1.479	21.70	1.311	26.47	45.5
August	0.572	18.51	1.904	27.94	1.238	24.99	48.0
Sept. 1–15	0.000	0.00	0.110	1.62	0.055	1.11	540.0
Sept. 16–30	0.000	0.00	0.000	0.00	0.000	0.00	....
	3.090	100.00	6.815	100.00	4.953	100.00	....

The seasonal net duty values presented in the preceding table are the results of investigations carried on by subdividing each tract into three parts; one part received the amount of water which the irrigator in his judgment deemed necessary, the other two parts received a smaller and larger amount of water respectively. The results are based on the net duty giving best yields in each case and within these limitations represent actual practice.

The seasonal duty for the different states of the arid region of the United States has been computed and assembled in the tables on pages 87 and 88. The values given are based on the measurements made and compiled by the Irrigation Investigations of the U. S. Department of Agriculture and on the duties obtained on a number of projects of the U. S. Reclamation Service.

The projects for which these seasonal duties are given are new projects which are still in the process of settlement. The water supply is ample; the percentages, therefore, represent very nearly the seasonal water requirements of the crops. With the exception of the Truckee Carson project and the Shoshone project the predominant crops on the other projects are the cereals (oats, wheat, barley); this accounts for the use and distribution of the greater part of the water during the months of June, July, and August with a maximum demand of more than 50 per cent. of the total supply in the month of July.

The values given are based on measurements of canal systems irrigating areas which are representative of large districts in each State:

In Arizona the seasonal duty on the Yuma Project is based on the use of water on an area supplied by three temporary pumping plants from an ample source, and therefore represents very nearly the variations in the water requirements of crops. The seasonal duty on the systems of the Salt River Valley is determined in the summer months by the limited water supply, and therefore is not in proportion to the water requirement of crops.

In California the Riverside Water Company's system serves an area about two-thirds in citrus fruit and one-third in alfalfa; the Gage Canal serves an area almost exclusively in citrus fruit; the seasonal duty for these systems represents the water requirement of citrus trees. The Modesto Turlock systems irrigate a large area in the San Joaquin Valley, of which 75 per cent. is

NET SEASONAL DUTY ON NINE PROJECTS OF U. S. RECLAMATION SERVICE, EXPRESSED IN PERCENTAGE OF NET DUTY

Project	Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Net duty, acre-feet per acre	Area in acres
Montana, Flathead	1911	.....	.....	.....	....	....	10.64	64.90	24.46	....	....	.....	.....	2.05	2,369
Montana, Huntley	1911	.....	.....	.....	....	5.67	12.37	45.35	27.32	9.28	....	.....	.....	1.94	12,000
Montana, Milk River	1911	.....	.....	.....	15.25	5.10	19.50	56.75	3.40	....	....	.....	.....	1.28	2,074
Montana, Sun River	1911	.....	.....	.....	....	3.38	21.62	57.10	16.22	1.35	....	.....	.....	1.58	6,892
Montana, No. Dakota, Lower Yellowstone.	1911	.....	.....	.....	....	0.71	26.95	63.82	5.67	1.42	1.42	.....	.....	1.41	15,400
Nevada, Truckee Carson*	1911	.....	.....	.....	16.60	17.55	19.75	18.90	12.90	10.60	3.70	.....	.....	4.50	30,139
North Dakota, Buford Trenton.	1911	.....	.....	.....	....	....	27.64	53.65	17.07	1.62	....	.....	.....	1.27	1,163
North Dakota, Williston	1911	.....	.....	.....	....	....	29.15	62.50	7.50	0.83	....	.....	.....	1.22	2,425
Wyoming, Shoshone	1911	.....	.....	.....	0.57	11.50	23.00	27.58	14.94	10.35	12.05	.....	.....	2.21	16,216
Mean for 8 U. S. R. S. Projects in Northern Division: Montana, Northern Wyoming, N. W. North Dakota.	...	.....	.....	.....	1.40	3.30	20.6	53.4	16.0	3.30	2.00	.....	.....	1.62	58,539

* Not included in mean.

GROSS SEASONAL DUTY FOR ARID STATES IN THE UNITED STATES

(Expressed in percentage of gross duty)

Project, period of measurement	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Gross duty, acre-feet per acre	Area in acres
Arizona, Yuma Project pumping plants, 1910–1911.	5.00	6.95	8.77	11.25	13.50	11.55	8.13	11.65	9.30	6.47	5.23	2.20	6.00	8,000
Arizona, Salt River Valley, several systems, 1895–1901.	7.90	11.80	13.25	12.35	8.45	4.00	5.40	8.90	6.60	7.05	7.05	7.25	....	......
Cal., Riverside Water Co., 1901–1908.........	5.37	2.01	3.40	7.73	12.71	11.96	11.88	11.75	10.61	8.25	7.38	6.95	2.29	9,000
Cal., Gage Canal, 1899–1901, 1902...........	3.50	5.35	7.90	9.66	10.04	9.90	10.00	10.62	10.24	10.05	7.33	5.41	2.16	7,000
Cal., Modesto-Turlock districts, 1911.........	.....	0.682	8.38	16.27	19.933	19.926	19.899	11.566	2.476	1.059	1.09	.....	4.58	106,062
Colo., Uncampahgre, various canals, 1910–1911	.....	......	8.00	18.00	20.2	17.6	14.9	13.3	8.0	......	.....	.....	6.7	25,000
Colo., Grand Valley Canal, 1901..............	.....	......	.....	......	15.1	19.6	22.0	15.7	13.8	13.8	.....	.....	4.109	21,800
Colo., Lake Canal, Arkansas Valley, 1901.....	.....	......	.....	......	29.0	47.50	8.6	10.1	14.8	......	.....	.....	2.582	14,500
Colo., Several canals, Big Thompson River, 1901	Jan.	to Apr	30	8.75	24.5	34.0	19.50	9.25	4.00	......	.....	.....	1.91	78,740
Idaho, 19 canal systems in Boise Valley, 1911..	.....	......	.....	7.9	19.0	21.3	21.0	13.2	11.9	5.7	.....	.....	4.07	131,617
Idaho, 9 canal systems, Boise Valley & Upper Snake River Valley, 1911, 1912.	.....	......	.....	5.93	16.35	22.05	22.92	15.44	12.60	4.21	.....	.....	5.258	48,500
Idaho, Part of Ridenbaugh Canal System, 1901	.....	......	.....	5.70	18.20	18.50	17.50	19.50	14.0	6.6	.....	.....	4.80	4,714
Mont., Big Ditch, Yellowstone Valley, 1900, 1901, 1902, 1903,	.....	......	.....	......	8.10	21.30	29.50	21.50	14.60	5.00	.....	.....	3.24	25,000
Mont., Middle Creek Canal Gallatin Valley, 1899, 1900, 1901, 1902, 1903	.....	......	.....	......	0.75	38.50	34.90	16.65	9.20	......	.....	.....	1.80	3,850
New Mexico, Average for the State as given by Territorial Engineer.	1.0	1.0	8.0	10.0	15.0	14.0	13.0	15.0	12.0	6.0	3.0	2.0	....	......
New Mexico, Pecos Canal, 1899, 1900, 1901...	.....	......	.....	......	8.50	15.2	19.2	17.9	20.9	13.1	5.2	.....	7.90	8,760
Oregon, Umatilla, 1910, 1911................	.....	......	2.20	13.0	16.9	19.2	19.5	18.0	10.0	1.2	.....	.....	16.35	3,000
Utah, Bear River Canal, 1901, 1905..........	.....	......	.....	......	14.5	23.0	18.5	17.5	12.3	13.0	1.2	.....	3.50	34,700
Wash. Sunnyside, 1898, 1902, 1904, 1906, 1909	.....	......	.....	7.65	14.92	16.0	18.68	20.42	13.8	8.53	.....	.....	....	......
Wyo., Canal No. 2, Wyo. Develop. Co., 1899–1900.	.....	......	.....	......	......	23.0	55.0	22.0	......	......	.....	.....	3.72	6,000
Rocky Mountain States—Colo., Wyo., Utah, Idaho; by J. C. Ulrich.	.....	......	.....	......	10.0	30.0	30.0	20.0	10.0	......	.....	.....	....	......

in alfalfa; the seasonal duty is given for a year when the water supply was more favorable than usual but not quite sufficient to meet the demand after the end of August.

In Colorado the Uncompahgre U. S. Reclamation Service project is in process of settlement; the water supply is ample and the seasonal duty is proportional to the needs of the crops, which in order of their importance are: alfalfa (44 per cent.), cereals, orchards, potatoes. The Grand Valley Canal has a plentiful source of supply, and the use of water represents the demand of water for the crops; the predominant crop is fruit, then alfalfa, sugar beets, grain. Lake Canal in the Arkansas Valley, because of a later water right, is entitled to water only when the other rights are satisfied; it has been necessary to raise crops adapted to the distribution of the water supply; the crops are alfalfa, grain and Mexican beans. The canals diverting from the Big Thompson River use also some stored water; the monthly percentages of use will about meet the variations in demand.

In Idaho the seasonal water requirement will be about as represented by the percentages given, which do not vary greatly for the different systems in the table.

In Montana the seasonal duty for Big Ditch of the Yellowstone Valley and the Middle Creek Canal of the Gallatin Valley represent the seasonal water requirement of crops not limited by a scanty water supply. The greater percentages in June and July for the Middle Creek Canal is probably due to the larger proportion of the total crop in cereals. For the Big Ditch the crop distribution was alfalfa and meadow, 75 per cent.; grain, 20 per cent.; other crops, 5 per cent.—for Middle Creek Canal, alfalfa, clover, timothy, 40 per cent.; grain, 55 per cent.; other crops, 5 per cent.

In New Mexico the values given by the Territorial Engineer, Vernon L. Sullivan, show approximately the average seasonal use of irrigation water in the State. The water supply of the Pecos Canal is partly regulated by storage and is abundant for the years of measurement, and therefore represents the seasonal water requirement of crops with an adequate supply.

In Oregon the Umatilla project has an ample water supply. The large volume of water used, as represented by the gross duty, is due to the greater part of the land, being a very porous sandy soil down to great depths, and to the newness of the canal

system. The seasonal duty represents the variation of the crop water requirement when not limited by a deficient water supply.

In Utah, Washington, and *Wyoming* the values given for the respective canal systems, Bear River Canal, Sunnyside Project, and Canal No. 2 Wyoming Development Co., represent the seasonal use with a water supply usually adequate. The large demand for the month of July in Wyoming is probably due to the large percentage of the crops in cereals (about 40 per cent.).

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CHAPTER VI

PREPARATION OF LAND FOR IRRIGATION AND METHOD OF APPLYING WATER TO THE LAND

The application of water to the land, by the usual methods of irrigation, requires that the land be prepared to permit the uniform distribution of water. The condition of the soil surface favorable to irrigation is a smooth slope, free from irregular depressions where water will collect, and free from knolls which cannot be uniformly wetted.

The floor of large valleys will usually present smooth surfaces with regular slopes well adapted to irrigation. In plains, benches or large valleys composed of a loose sandy soil bare and unprotected, the velocity of the wind may be sufficient to cause sand drifts, making the soil surface into ridges, knolls and depressions. In the upper part of valleys, especially small valleys, in the foothills and in the benches along rivers, the weathering action of rains and running water may have formed rolling land with more or less irregular slopes cut up by channels and gullies.

The steps involved in the preparation of the land for irrigation are:

First: Clearing the surface of native vegetation.

Second: Smoothing and leveling of the surface.

Third: Construction of distribution system, based on method of irrigation.

CLEARING LAND OF NATIVE VEGETATION

A considerable part of lands placed under irrigation is either land on which the native vegetation consists of grasses or small brush thinly scattered, or dry farmland. There are, however, large areas where the native vegetation may be large brush or even small trees, whose removal involves considerable labor and expenditure. The most common forms of vegetation are: The sage brush, greasewood, cactus, chaparral, scrub oak, the larger

growth of mesquite, cedar piñon, pines, or other trees, and the remaining stumps on logged off lands.

When the native vegetation is small brush, it may be removed by plowing deeply, and then pulling the brush by hand or raking it together in windrows to be burned. The best time to plow up brush is in the spring when the moist soil plows easily and when the roots, full of sap, are easy to cut. Where the vegetation is tall sage brush, thinly scattered, it may be grubbed out by hand with a mattock. Thick growth of dry sage brush may be burned off while standing. A common practice in Colorado, Wyoming, and Utah has been to kill sage brush or check its growth by heavy irrigations for one season. The dead sage brush is easily removed and the irrigation produces a growth of grass and weeds which, when dry, facilitates the burning of the brush. This method requires that the land be sufficiently regular and smooth to be irrigated and that an ample water supply be available. The increase in value of water and the time necessary to destroy the sage brush are conditions which limit its general adoption.

A method largely used to remove brush is commonly known as railing. The brush is broken off by means of a 60-pound railroad rail, 12 to 16 feet long, or heavy timber shod with steel and drawn over the land, first in one direction and then in the opposite direction. Sometimes the rail is bent to a V-shape to give more power in breaking and pulling out the brush. Two rails bolted together are commonly used in Idaho. The best time for this work is when the ground is frozen. The greater part of the brush breaks off at or below the surface; the remainder must be grubbed out with mattocks by hand; it is then raked into windrows or piles and burned. Large brush or small trees such as mesquite, chaparral, manzanita, piñon can be grubbed out, but it is more economically pulled out by a team of strong horses with the use either of a logging chain or stump puller.

On very loose, light, sandy soils, such as found in sections of eastern Washington and eastern Oregon, considerable difficulty is experienced in clearing and seeding new lands because of the wind action which carries the loose sand, removing the seeds or cutting the new plants from the soil and filling the ditches. To overcome this, the practice in the Umatilla country, in eastern Oregon, is to clear the sage brush by grubbing by hand, because this loosens the soil less than by railing, and the sage brush is

raked or stacked in rows 30 to 60 feet apart, at right angles to the direction of prevailing winds, and left there temporarily to act as wind brakes and protect the soil. The land is cleared and graded, preferably in small areas which can be quickly seeded and irrigated before being exposed to strong wind action. Where straw or manure is available to cover the newly cleared land, it will form an efficient protection against the wind erosion. A practice which has given good results is to plant rye for the first crop; the seed is put in by drill, usually in August or September, when the weather is not so warm that it will wither the young plants, at the rate of 50 to 60 pounds per acre, and is given one irrigation. This first crop will come up early, will stand against the cutting action of the blowing sand better than other crops, and protect the soil; alfalfa or another crop may be seeded in the standing crop of rye when it is 3 or 4 inches high or in the stubble after the rye has been cut.

Timbered land which is to come under irrigation is seldom heavily timbered. The first operation is the felling of the trees, which are used for lumber, firewood or fence posts, the value of which may partly pay for the cost of clearing. The second operation, which applies equally well to logged off land, is the removal of the stumps. This may be done by various methods, but the process is always expensive. It may be done: First, by hand with shovels, picks, mattocks, and axes. Second, by the use of stump pullers worked by horses. Third, by the use of donkey engine outfit. Fourth, by the use of powder, either to blow the stumps out of the ground or to split them and loosen them for the removal with stump pullers or donkey engines. Fifth, by the burning method, which consists of boring a single slanting hole, or two intersecting holes, at the foot of the stump, into which a fire is built and regulated until it has burned the stump down into the roots to a depth of 12 to 14 inches. Sixth, by the char pit method. This last method, which has become better known recently, has given very good results with soils containing considerable clay. The cost of removing stumps in the State of Washington by this method was found to vary from 25 cents to $1.00 each for stumps as large as 40 inches in diameter. The method has been fully described in General Bulletin 101 of the Agricultural Experiment Station of Washington State College, Pullman, Washington; and also described with the other methods

Cost and Method of Clearing Land in Western Washington, by Harry Thompson, Bulletin 239, Bureau of Plant Industry, U. S. Department of Agriculture.

SMOOTHING AND LEVELLING OF THE SURFACE

The object of this operation is the shaping of the surface to permit the application to the land of water supplied from a system of distributaries. When the work has been well done, the water will be easily and uniformly distributed over the land and the waste of water will be a minimum. When the work is poorly done, leaving the surface more or less rough and irregular, it will require more labor to distribute the water; low spots will receive an excess of water and high knolls will not be wetted sufficiently; some parts of the land will receive more water than others with a waste by deep percolation; the result will be increased cost of distribution, waste of water, and unequal and poor crop production. The extra cost of a well graded surface will be more than repaid by the better results.

The amount of earth work in grading and the methods used will depend on the character of land, the surface, and the methods of irrigation. Some methods of irrigation require only a fairly smooth surface, having a continuous downward slope, whose grade may be variable but should be preferably uniform and not too steep. Other methods require that the land be shaped into basins or checks of perfectly levelled land.

The preparation of the land surface must be adapted to the method of irrigation and should be preceded by the planning and location of the position most favorable to good distribution. It is usually preferable that at least the permanent parts of the distribution system be first constructed and that the land be shaped accordingly.

The methods of irrigation and the different forms of ditches and distributaries will be considered, after a description of the methods and devices used in the shaping of the earth surface. Lands which have been plowed to remove the native vegetation must be thoroughly harrowed before grading. For loose soils, plowing before grading is not necessary; for heavier compact soils, the surface to be scraped off must be loosened by disking for light cuts or by plowing for heavier cuts.

The topography of the surface must be carefully examined to determine the ridges and knolls from which the soil will be scraped to fill the depressions. Where the land must be graded to a true level surface, as for some methods of irrigation, a contour survey is desirable.

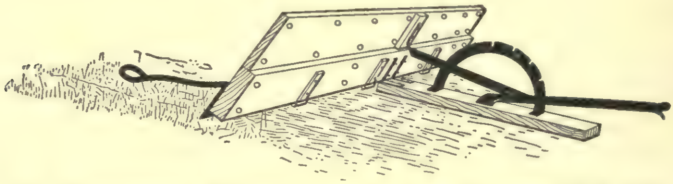

Fig. 18.—Buck scraper for leveling land. From Farmers' Bull. 373, U. S. Dept. of Agriculture.

There is a large variety of implements used for surface grading. The type best suited will depend largely on the amount of earthwork. Where the irregularities consist of knolls and ridges of considerable height, and where the soil must be transported for a

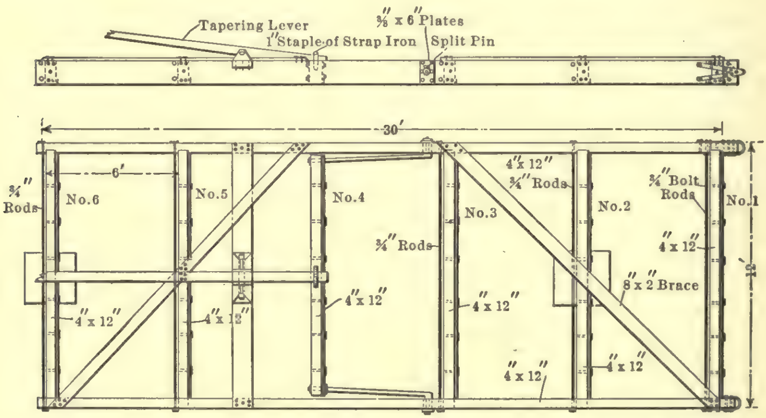

Fig. 19.—Rectangular leveler. From Farmers' Bull. 392, U. S. Dept. of Agriculture.

considerable distance, the Fresno Scraper (Plate I, Fig. B) or some form of scraper on wheels is the best implement. Where the surface is not so rough and the hauls are short, a tool which is commonly used is known as the Buck Scraper, Fig. 18. It is best suited to sandy soils and is used extensively in the Yakima Valley

of Eastern Washington and in Eastern Oregon. It consists of a scraper board 10 to 16 feet long, and 2 feet wide, made of 2 inch plank, shod along one edge with a steel plate, and a tailboard or footboard with the necessary lever handle and connections to regulate the angle of the scraper board and to hold it in position. The smaller size requires four horses and the larger six horses.

For land where the irregularities consist of knolls or hummocks fairly uniform in size, not too large, and distributed rather uniformly so that the scraped off material must not be carried far, an implement used with much success in the Imperial Valley of Southern California is the Rectangular Scraper or leveller, Fig. 19. It is a rectangular frame 30 feet long and 12 feet wide, in

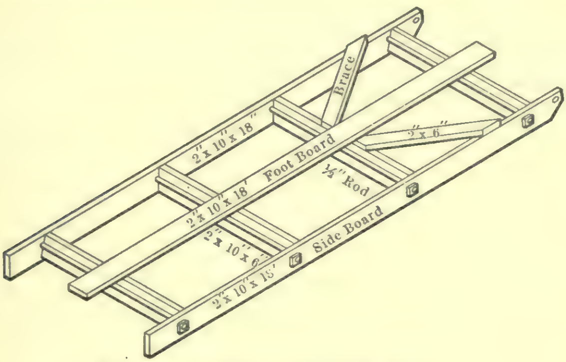

Fig. 20.—Float for leveling land.

which are assembled six scrapers. The sides of the frame are made of 4 to 12-inch timbers 30 feet long, placed on edge. The two ends of the frame with the four intermediate cross-pieces are the scrapers; they are made of 4 by 12 timber, 12 feet long, placed on edge, with the lower part of the wearing side shod with a steel plate, 3/8 inch thick by 6 inches wide. All of the scrapers excepting the fourth one from the head end are fastened to the side timbers and have iron tightening rods on one side of them. The fourth scraper, which is movable, is held by rods and connected to a lever which regulates its depth of scraping. The machine is strongly constructed, and weighs nearly 2,000 pounds; it requires sixteen horses, and will remove shrubs, roots, and cut down the hummocks. The

scrapers described above are especially adapted to the preparation of comparatively rough and uneven land which requires considerable earthwork, and unless skilfully done leaves the surface with small unevenness, which requires final smoothing. For this final finishing and for the grading of land, which in its natural state is fairly smooth, the implements used are some form of leveler or drag. Before these are used, the land must be plowed deeply and harrowed thoroughly. The leveler or drag

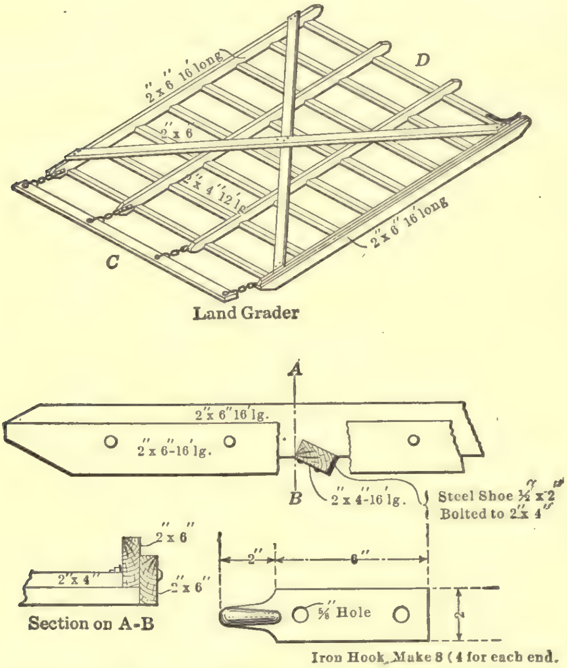

FIG. 21.—Homemade land grader. From O. E. S. Bull. 145, U. S. Dept. of Agriculture.

is then drawn across the field usually in both directions. The simplest kind of smoother may consist of a log 6 to 8 inches in diameter connected to a tongue. A more satisfactory form is a rectangular smoother or float, Fig. 20, made of 2 by 10 inch timber, using two side pieces 16 to 20 feet long, 5 to 8 feet apart, to which are fastened 4 or 5 cross pieces 5 to 8 feet long. The two end cross pieces are inclined backward with the lower

edge raised 2 inches above the bottom of the sides to prevent cutting too deeply into the earth. To hold the cross pieces, an iron rod with bolt heads is placed along each cross piece and cross braces give the necessary rigidity. To stand the wear, a steel

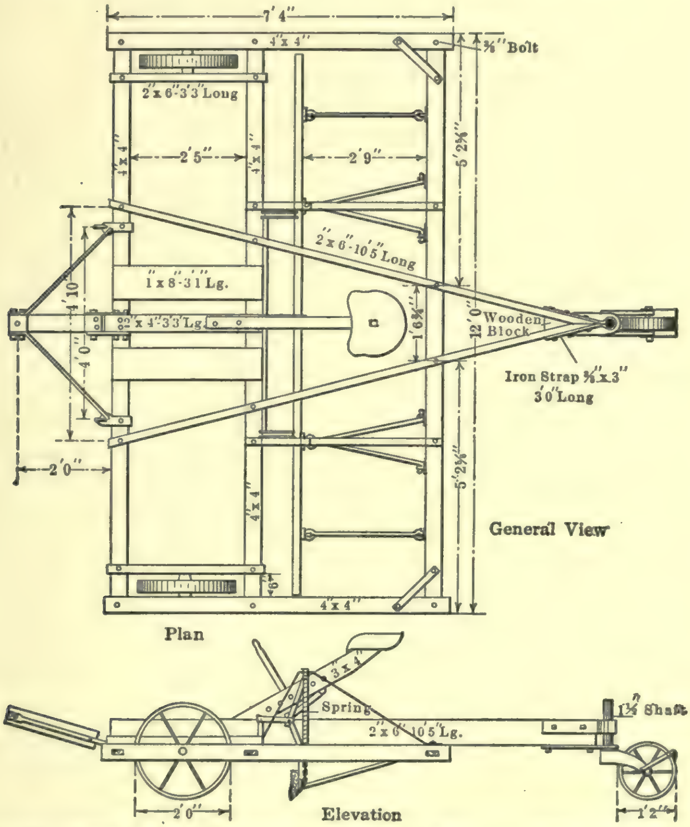

FIG. 22.—Leveler used in Gallatin Valley, Montana. From Farmers' Bull. 373, U. S. Dept. of Agriculture.

or iron facing on the cutting face is necessary. A width of 5 feet is best for four horses.

A larger form of rectangular leveler and grader, and a form of home-made leveler on wheels for final smoothing, used in the Gallatin Valley in Montana, are illustrated by the accompanying sketches, Figs. 21 and 22.

METHODS OF APPLYING WATER TO LAND

The method of irrigation best adapted to special conditions will depend on the kind of crop, the lay of the land, the character of water supply and head of water delivered to the irrigator, and the kind of soil.

The methods commonly used are:

1st. The wild flooding or free flooding method.
2nd. The border method of flooding.
3rd. Check flooding method.
4th. Basin method.
5th. Furrow method.
6th. Pipe method.

Wild Flooding Method.—This method is extensively used in the Rocky Mountain States of Colorado, Montana, Utah, and Wyoming, for the irrigation of grain, alfalfa, clover, and meadows. It requires less grading than other methods of flooding, it is adapted to smaller heads of water than the border or check method of irrigation, and is better suited to land having considerable slope and to irregular hillsides. The surface must be prepared by removing the knolls and filling the depressions, so as to obtain a smooth surface; for slopes which are not irregular, very little grading is necessary. The water is obtained from a system of permanent main supply ditches, located along the higher boundaries of the field or on the ridges; and of parallel field ditches or distributaries, placed at regular intervals. Each field ditch serves a strip of land, which is irrigated by checking the flow of water in the field ditch at intervals, so as to make the water pass over the bank or through cuts made in the bank of the ditch, and flood the land with over-lapping sheets of water which move slowly down the slope. The field ditches, when the crop irrigated is grain, are usually filled in each year before harvesting. For other crops they are usually left opened.

The relative location of the main supply ditch and the field ditches will depend on the texture of the soil and the surface slope. One method is to place the supply ditch down the steepest slope and the field ditches on a flat grade across the slope, Fig. 23. The water when checked in the field ditch, overflows the downhill bank and spreads as a sheet, moving slowly down to the next lower field ditch, which collects the excess or waste water.

Another method is obtained by placing the supply ditch on a flat grade across the steepest slope, and to run the field ditches nearly at right angles to the contours down the steepest slope, Fig. 24. The water is turned out from the field ditch by checking the water at intervals and diverting it through a cut in each bank, made above the check or dam. The water spreads laterally and also

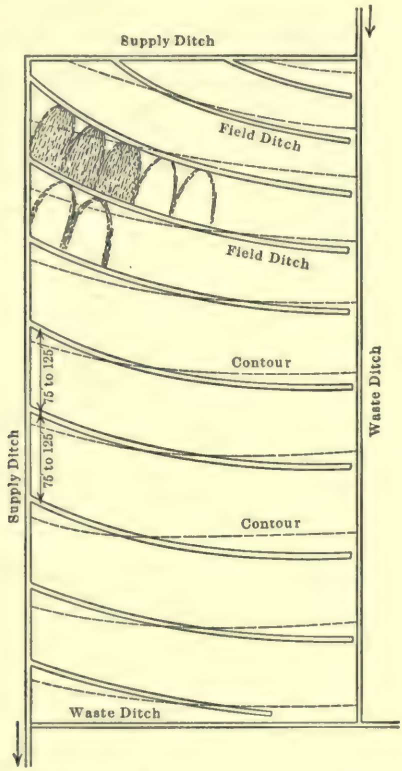

Fig. 23.—Flooding from field ditches running on flat grade.

down the slope parallel with the field ditches. On land where the slope is excessive, the water will spread laterally only a short distance and the field ditches must be close together.

A third method is obtained when the ditches are placed in a position intermediate between the position in the other two methods. The main supply ditch and the field ditches are placed so that the grade of the field ditches is about twice that at right angles to

them; this will make the sheet of water travel half as far toward the next field ditch as it does in the direction parallel to the field ditch. For steep slopes, this is preferable to the second method, which would produce a too rapid flow parallel with the field ditch without sufficient spread laterally.

It is practically impossible to eliminate entirely a certain amount of waste water at the lower end of the field; to collect this water and prevent the flooding of roads or the adjoining farm below, each field should be provided with a drain or waste ditch along the lower boundary. In addition, drain ditches may be necessary to connect the natural depressions where waste water accumulates. These drain ditches deliver into a main drain or an irrigation lateral below.

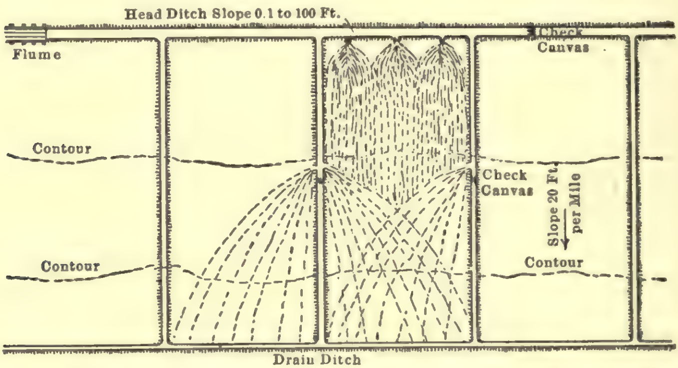

FIG. 24.—Wild flooding from field ditches running down steepest slope. From Farmers' Bull. 399, U. S. Dept. of Agriculture.

The distance apart of the field ditches varies from about 30 feet to 200 feet or more. To prevent waste by deep percolation and to obtain a more uniform irrigation, it is best to have the field ditches close together. A spacing of about 75 to 125 feet may be taken for a desirable average. Sandy soils require a closer spacing than clay soils, unless a smaller head of water is used for the clay soil. To distribute the water, it is diverted to the field ditches in turn, beginning at the upper end of the supply ditch. The flow down the supply ditch is stopped, and the water level raised to deliver into the heads of the field ditches by permanent check gates of wood or concrete, built across the supply ditch, or by temporary dams of manure, earth, canvas, or metal, Fig. 27. When the

grade of the supply ditch is small a single dam may raise the water level for sufficient distance upstream, to include the head of a number of field ditches. For steeper grades a dam or check

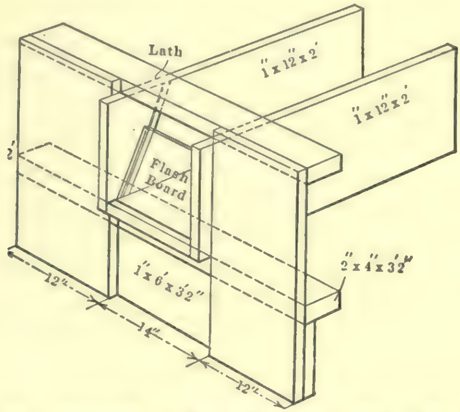

Fig. 25.—Wooden checkgate. From Farmers' Bull. 404, U. S. Dept. of Agriculture.

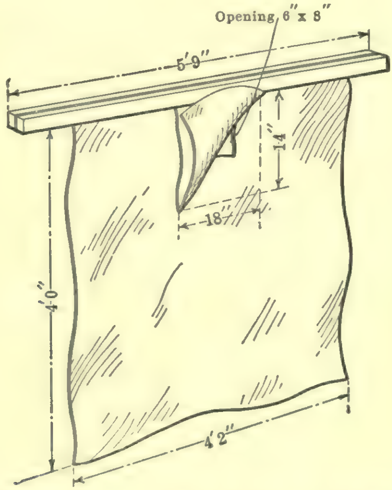

Fig. 26.—Canvas dam with opening to divide an irrigating stream. From O. E. S. Bull. 145, U. S. Dept. of Agriculture.

gate may be necessary below the head of each field ditch, and if more than one field ditch is supplied at the same time, the dam must allow part of the flow to pass on to the one or two field

ditches below; for this, a permanent check gate, Fig. 25, a canvas dam, Fig. 26, or a steel dam, Fig. 28, with an opening, are the best devices. To apply the water from the field ditches to the land, beginning at the upper end of the field ditch, the flow of water down the ditch is stopped by a temporary dam, which forces the water to run over the downhill bank or through cuts in the bank above the dam. When the piece of land above the dam has been flooded, the dam is removed, and the irrigation of the next section below proceeds in the same manner. The dams, which are made of manure, earth, canvas, or steel, are placed at intervals of 60 to 100 feet. The quantity of water or head carried in a field ditch is usually about 1 cubic foot per second (40 to 50 miner's inches). The volume delivered to the farm and carried by the supply ditch ranges from 1 to 3 cubic feet per second, and is divided into two or three field ditches. An experienced irri-

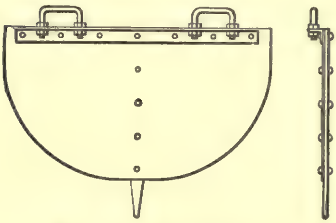

Fig. 27.—Steel dam.

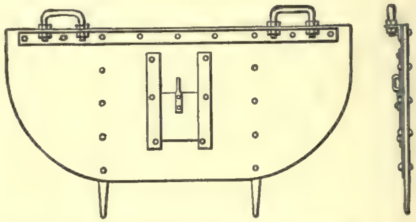

Fig. 28.—Steel dam with opening.

gator may handle as much as 3 to 4 second feet, distributed into 3 field ditches; 2 second feet represent more nearly the head of water which an average irrigator can handle. With a continuous flow of 2 or 3 cubic feet per second, two men each working 1/2 day will irrigate 8 to 12 acres; and with 4 cubic feet as much as 16 to 20 acres. The form and size of supply ditches and field ditches depend on the volume of water to be carried, the character of the soil, the grade of the ditch, the method of construction, and will be discussed in the following chapter.

The field ditches usually carry from 1 to 1 1/2 cubic feet per second. When placed across the slope, a flat grade is very desirable, in order to obtain an even overflow over the downhill bank when the water is checked at intervals. A minimum grade of 1/2 to 1 inch in 100 feet is sufficient; grades of 3 to 6 inches are more desirable and more generally used. When placed down

the steepest grade, there is danger of soil erosion by too high a velocity. The desirable maximum velocity may be as low as 1 foot per second or even less for very loose light soils. By using a smaller head, lower velocities will be obtained. For very light soils a grade of 10 to 15 feet per mile may be the maximum; for heavier soils, grades of 25 to 50 or even 100 feet per mile may not be excessive.

Border Method of Flooding.—Fig. 29. This method is used for the irrigation of alfalfa and cereals. It has been adopted very extensively in Arizona, in the Imperial Valley, San Joaquin and Sacramento Valley in California, and its use is spreading to the other States.

The method, which is an improvement on the wild flooding method, consists in shaping the land in long narrow strips, extending lengthwise down the natural slope and separated by parallel ridges or borders, which confine the sheet of water within the strip, as it runs down the slope. Usually the strips are ended at the lower end by a cross levee or by the uphill bank of the next supply ditch. For the heavier soils at least it is desirable to provide drain ditches at the lower end in order to remove excess water, which if allowed to stand on the land may damage the crop. It requires careful smoothing of the land to make each strip level transversely, and with a uniform slope longitudinally. After the necessary clearing, the ditches are planned and excavated; then the levees for the borders are marked and constructed; and finally the land surface between borders is made smooth. This procedure will avoid moving the dirt more than once, and in that way is preferable to smoothing the land first, then building the levees and finally excavating the ditches. The knolls may be scraped to obtain material for excess fill in ditches, to fill depressions and give additional material where necessary to form the levees. The soil is usually loosened by plowing and the levees are formed by one of two methods. In the first method the soil is thrown together on the line marked for the border levee, by running two to four furrows and bringing the loose earth into a smooth ridge by means of a ridger or crowder, Fig. 33. The removal of the earth to form the ridges leaves a shallow depression on each side of the ridge, which can be filled by running a smoother or leveler across the strip. Another method, which is usually considered preferable, is to skim the surface transversally to the direction of

the ridges and dump sufficient soil at the border marking to form the ridges (Plate II, Fig. A), which are smoothed over with a levee smoother, Fig. 30, run lengthwise.

The importance of careful preparation of the land cannot be

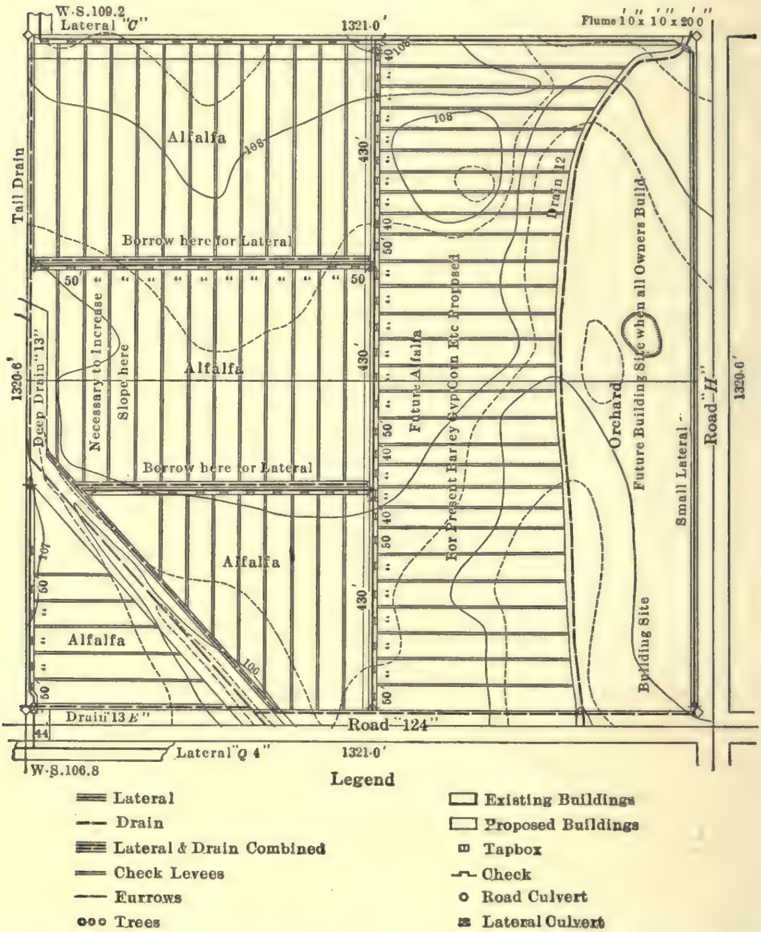

FIG. 29.—Farm laid out for border method of irrigation. Sacramento Valley Irrigation Project farm development system, Lot 529 Jacinto Unit.

overestimated; to insure that the land has been properly prepared, it is very desirable to apply one irrigation before the crop is planted. This will settle the loose soil and show any defects, which can be remedied easily and cheaply before planting.

FIG. A.—Constructing levee for check method of flooding, with Fresno scraper.

FIG. B.—Basin method of orchard irrigation.

(*Facing Page* 106.)

PLATE II

FIG. C.—Furrow method of irrigation in orchard.

FIG. D.—Making furrows with modified wheeled cultivator.

The water is carried to each strip by the supply ditch or head ditch, placed along the upper edge of each strip. The flow down the head ditch is checked by means of dams of canvas or metal, or by a permanent check gate of wood or concrete, and delivered to each strip through permanent border gates placed in the bank, which regulate the flow, or through cuts made in the bank. The flow is shut off in time to leave sufficient water to reach the lower end. The dimensions of the strip depend on the texture of the soil, the slope lengthwise with the strip, and the head of water. Long strips will produce excessive percolation

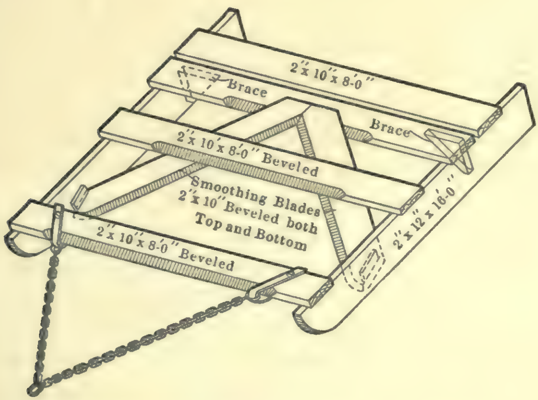

Fig. 30.—Levee smoother. From Farmers' Bull. 373, U. S. Dept. of Agriculture.

at the upper end, which will be greatest on sandy soils and for small heads. The effect of length of runs and head of water on the deep percolation loss was well illustrated by the data presented under the subject of percolation losses.

In practice, the slope down the strip varies from a flat grade of 1 foot in 1,000 or even less for short strips to a maximum for longer strips of 1 foot in 100 feet for a medium soil; slopes of 1 foot in 300 to 500 feet are generally best. Where the slope is excessive, the strips may be run diagonally to the steepest slope; this, however, increases the amount of earthwork to shape the land. With steep slopes, the water has a tendency to move down

the slope too rapidly without spreading sufficiently laterally; a smaller head and narrower strips are advisable to give sufficient time for the water to percolate. For land on nearly level grade, the width of strips should be made wider and the length decreased; and to force the water to the lower end, the ridges must be made higher. The practice in various localities is illustrated by the following examples:

In the Imperial Valley, California, the width of strips ranges from 40 to 100 feet, averaging usually 50 to 60, and the length from 660 to 1,320 feet; the natural slope of the land is from 1 to 5 feet per mile; the soil is a fairly tight clay loam, and to obtain a sufficient depth of wetting, must be irrigated by passing the water down the slope slowly—this is obtained by using comparatively small heads of 1 cubic foot per second for fairly tight loam to 3 cubic feet per second for a more sandy loam for each strip.

On some unusually heavy clay soils of the Sacramento Valley it was found difficult to get the moisture to penetrate down to a sufficient depth; this was satisfactorily obtained by dividing the irrigation head of 5 cubic feet per second into 10 or 15 strips, and applying two irrigations in succession; the second irrigation being applied before the soil surface had dried out. The strips were 30 to 50 feet wide and 660 feet long.

In Yolo County, in the Sacramento Valley, California, the soil is a sandy loam; the width of strips ranges from 35 feet for a steep grade of 1 in 100 to a width of 50 feet for a more prevalent grade of 1 in 440 feet; the length varies from 660 to 1,320 feet. The volume of water delivered by the irrigation company is usually from 15 to 20 cubic feet per second, which is divided into heads of 4 to 6 cubic feet per second for each strip. On land irrigated by pumping plants, the same sized strip is irrigated with heads of 2 second feet, but it is usually preferred to use smaller strips.

In the Modesto district and Turlock districts, in the San Joaquin Valley of California, the width varies from 30 to 100 feet and the length from 150 to 2,640 feet; a width of 50 to 75 feet and a length of from 300 to 1,320 feet are considered best; the grade ranges from nearly level to a maximum of 1 foot in 100; the best grade is 2 to 4 inches in 100 feet. The greater part of the soil is a sandy loam, which requires a good head for satisfactory irrigation.

The head generally used, ranges from about 10 to 20 second feet; an order passed by the Modesto district fixes the minimum head at 15 second feet and limits the time of use to 20 minutes per acre. The head is sometimes divided to be used on two or three checks at the same time.

In the vicinity of Merced, California, sandy loam soils supplied by pumping plants are irrigated with as small a head as 1 to 2 second feet, with small checks 30 feet wide and 330 feet long.

In the Salt River Valley of Arizona, the strips are 30 to 50 feet wide, and 660 to 1,320 feet long. In the Rillito Valley, Arizona, checks 30 feet by 660 feet are irrigated with heads of about 2 second feet.

In general, heads of at least 2 to 3 cubic feet per second are necessary for the heavier soils on a good grade, and preferably heads of 4 to 6 cubic feet per second; for sandy open soils, heads of 6 to 15 cubic feet per second are usually desirable for ordinary size checks. The width of levees ranges from 3 to 10 feet, and the height from 9 inches to 15 inches. A height of 12 inches, which will settle to 9 or 10 inches, and a width of 6 to 8 feet may be taken as good averages. The dimensions of the supply ditches and the design and construction of levee gates and check gates are considered in the next chapter.

Check Method of Flooding.—This method is extensively used in California, Arizona, and New Mexico for the irrigation of alfalfa, to a more limited extent for cereals, and in some sections of California for sugar beets, and other crops. It permits the handling of large volumes of water, which makes it well adapted to winter irrigation or to the application of flood water from streams which carry a large volume of water for a short time only, with a deficient supply later. The conditions favorable to this method of irrigation are an even grade of 3 to 15 feet per mile and a head of water of at least 5 cubic feet per second. It is well adapted to heavy soils as well as to lighter sandy soils.

To prepare the land for irrigation, a system of supply ditches is constructed and the field is divided and formed by grading into level checks or basins, surrounded by levees. The water is delivered through levee gates placed in the levees. Two forms of checks are used: the rectangular checks and the contour checks, Fig. 31. Rectangular checks are formed by placing the longitudinal levees in straight lines across the slope in the gen-

eral direction of the contours and the cross levees at right angles. Contour checks are formed by longitudinal levees ajdusted by more or less irregular curves to conform more nearly

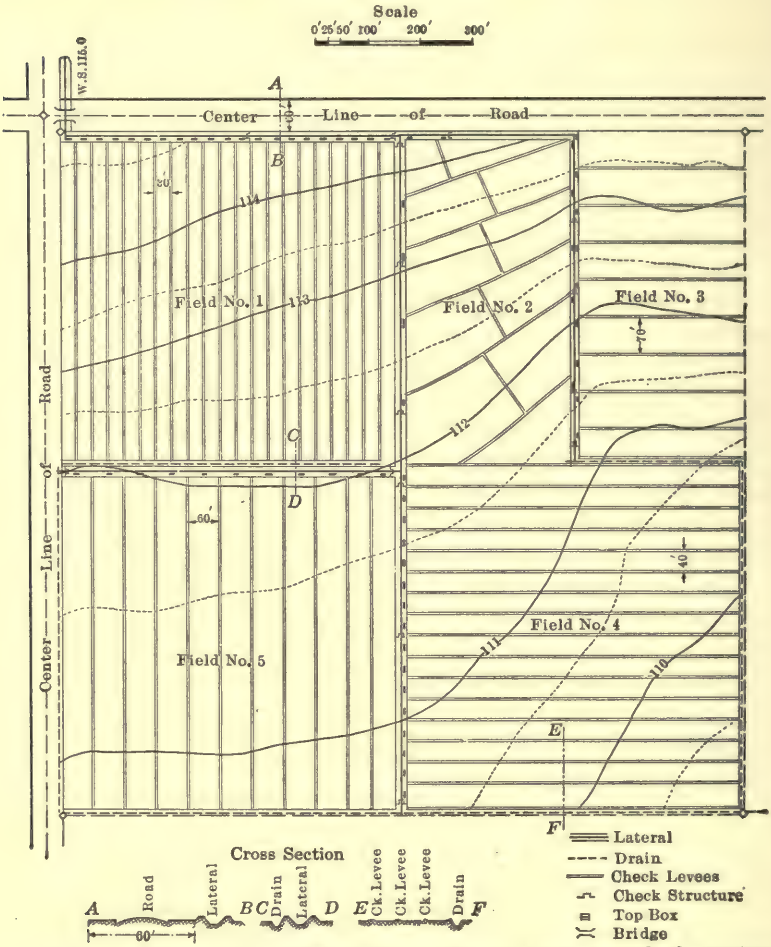

FIG. 31.—Farm plan showing adaptation of border method, contour check method and rectangular check method of irrigation. Sacramento Valley Irrigation Project farm development system.

with the contours, and by cross levees to divide the strips between longitudinal levees into suitable areas, Fig. 32. Rectangular checks require more earthwork than contour checks, but

conform to fence lines and may facilitate field operations; they are better adapted to even slopes where the contours are nearly straight lines. On irregular slopes the contour checks are fitted with less earthwork and do not remove the surface soil on the

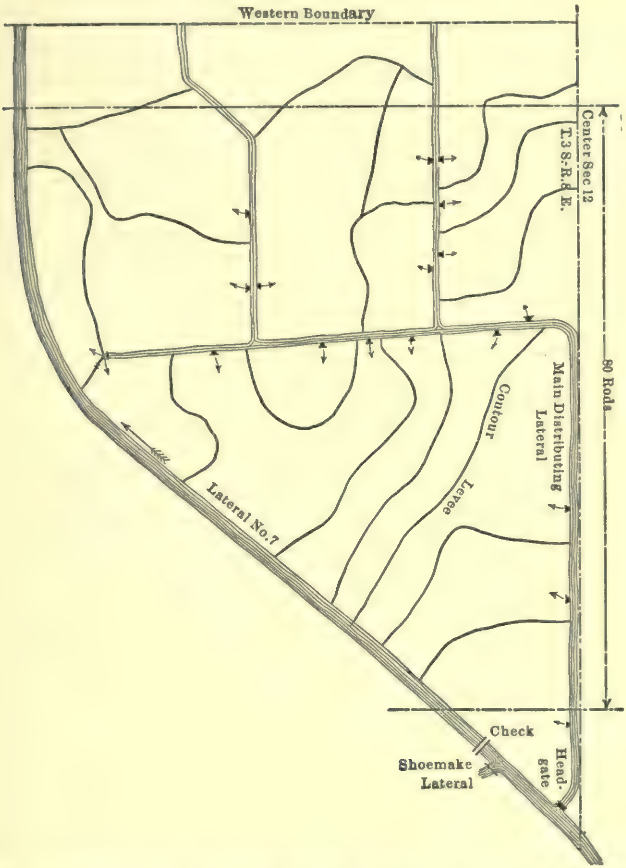

FIG. 32.—Irrigation by contour check system. From O. E. S. Bull. 158, U. S. Dept. of Agriculture.

high side of the check to the same extent as rectangular checks. The size of the checks will depend on the soil and the head of water; as the checks are usually made practically level, or with a very flat slope of 2 to 4 inches lengthwise, it is necessary to spread the water over them quickly to prevent excess perco-

lation at the point of delivery into the check; this requires a comparatively small check which can be more easily brought to a true level surface. The size varies from 1/2 acre or less to 10 or more acres, the general average is from 1/2 to 3 acres, and 3/4 to 1 1/2 acres is generally considered as the desirable size.

On land with uneven slopes the shape of contour checks may be quite irregular, but on fairly smooth land will usually be an elongate strip. The width of the checks across the contours is fixed by the difference in elevation between adjacent checks, which it is desirable to keep small in order to decrease the amount of earthwork. On steep slopes the difference in elevation should not exceed 6 to 9 inches and for ordinary slopes should preferably be from 2 to 4 inches. For a slope of 25 feet to the mile the width of checks is 110 feet for 6 inches difference in elevation. Land with a slope of 50 feet to the mile or more is preferably irrigated by some other method. The levees must be made broad and low to facilitate the passage of farming machinery over them and the harvesting of crops grown on the levees, and to wet the soil sufficiently. A settled height of the crown of the levee above the surface of the uphill check of 9 to 10 inches and a base width of 10 to 12 feet is generally best.

The levees are made in much the same manner as for border irrigation; by scraping the high knolls and depositing the material along the marked position of the levees, Plate II, Fig. A.

To distribute the water, the best method is to provide a supply ditch for groups of checks on each side; the flow down the ditch can be stopped and the water level raised to deliver the head through gates of wood or concrete, placed in the banks of the ditch. To decrease the cost, fewer supply ditches are sometimes used, the water is then delivered to the upper check of a group of checks extending down the slope, and is passed to the adjacent checks lower down by making an opening in the downhill levee, or by overflowing the levee; this operation is repeated in turn for the lower checks. The openings in the levees must not be made in line, which might wash out a channel through the checks, but made preferably at opposite ends of the checks. This method is very liable to give unequal distribution of water with an excess in the upper checks.

The ditches must be made of sufficient capacity to carry the head of water which ranges from 5 to 20 cubic feet per second.

For small checks the head can be divided to deliver 5 cubic feet per second to each check. The gates through the levees are made of wood or concrete and the openings are from 3 to 9 feet wide; a width of 6 feet is a good average. The size and construction of supply ditches and the design and construction of levee gates and check gates are considered in Chapter VII.

Basin Method.—This method, which is the check method adapted to the irrigation of orchards, is used in parts of California, Arizona and New Mexico. It enables the application of large quantities of water in a short time, by the use of a comparatively large head of water, and for that reason finds its best use in the application of flood waters or winter irrigation.

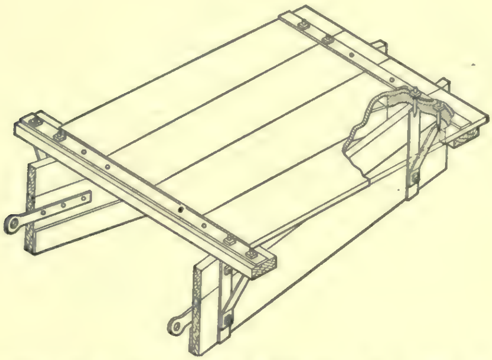

FIG. 33.—Adjustable ridger. From Farmers' Bull. 373, U. S. Dept. of Agriculture.

The method requires that the land be properly shaped before each irrigation. This consists in forming a basin usually for each tree, Plate II, Fig. B, although on level land two, four or more trees may be included by ridges or levees midway between the tree rows in both directions. The ridges are made by throwing two furrows together, or by loosening the soil with a disk plow, followed by a ridger which crowds the loose soil together, Fig. 33. On loose sandy soil the use of the ridger alone may be sufficient. A common form of ridger is made of two side runners, made of 2-inch lumber, 14 to 18 inches high and 5 to 8 feet long, spaced 4 to 5-feet. apart at the front end and 15 to 24 inches at the rear end. These are held together by cross pieces and a cover placed on top, and connected together with straps of steel. After running

the ridger in both directions, the openings left at the intersection of the ridges must be closed. This may be done by hand or with a scraper. The height of ridges varies from 8 to 12 inches, depending on the depth of water.

The most satisfactory way of conveying and applying the water to each basin is by means of a main permanent supply ditch along the upper end of the orchard, and a system of parallel distributary ditches, running at right angles to the main supply ditch and connected to it at the upper end, Fig. 34. Each distributary ditch is made in the alternate space between tree rows and serves a tier of basins on each side. The flow of water in the main ditch and down the distributary is regulated and checked with metal tappoons or canvas dams, and the water diverted into

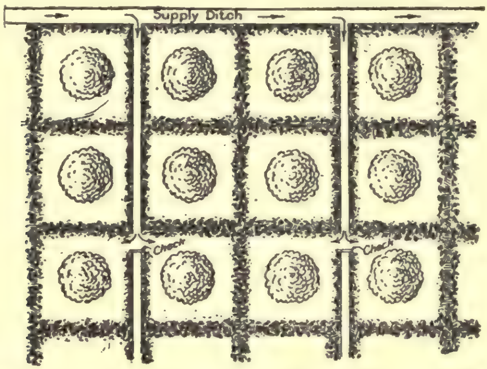

FIG. 34.—Basin method of irrigation. From Farmers' Bull. 404, U. S. Dept. of Agriculture.

each basin through a cut made in the ditch bank at the upper corner of the basin.

Another method is to do without the parallel distributary ditches. The water is diverted from the supply ditch along the upper edge of the orchard into the first basin, and passes from this basin into the lower basins of the tier, through openings in opposite corners to give the water a zigzag course, Fig. 35. This method is sometimes modified by passing the water from one basin into the next by letting it overflow the intervening ridge. These methods are not as satisfactory as the first, for they give an excess of water to the upper basin.

To protect the trunk of the trees from contact with the water

which is considered harmful by some orchardists, one practice is to form an inner basin by building another set of ridges in both directions. Another practice consists in grading the land so as to leave the soil around the tree higher than in the remainder of the basin.

The basin method when properly used will give a more equal distribution of water on the land than the furrow method, but it has the disadvantage that it may cause baking of the surface, will give a greater evaporation loss from the surface, and requires considerable labor for the construction of ridges and distributary ditches, which are temporary and removed by the cultivation following the irrigation.

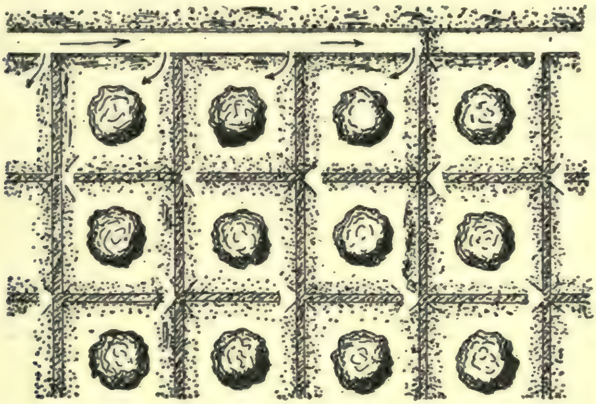

Fig. 35.—Irrigating orchard by basin method. From Farmers' Bull. 404, U. S. Dept. of Agriculture.

Furrow Method of Irrigation, Plate II, Fig. C.—The furrow method of irrigation consists in applying the water to the land by running into furrows, properly spaced, small streams of water until the soil is sufficiently moistened. It is used for the irrigation of all crops grown in rows. It is used extensively in Washington, and to a more limited extent in Idaho, for the irrigation of alfalfa and of grain. For uniform distribution of water, the furrows must be spaced sufficiently close to produce the correct degree of moisture in the soil containing the root system of the plants, by the lateral movement of water on each side of the furrow; the furrows must not be excessively long in order to minimize

the loss by deep percolation, and the stream run into each furrow must be properly controlled and regulated.

The water is conveyed to the head of the furrows through a system of head ditches, flumes, or pipes, which subdivide the orchard or field into strips or sections, which can be irrigated by furrows of suitable length. The length of the furrows ranges usually from 330 to 1,320 feet. As a rule, for ordinary sandy loam, the length should not exceed 600 feet and preferably 330 feet; and for porous sandy soils, not over 330 feet and preferably 200 feet or less.

The grade of the furrows varies with the topography or lay of the land. On flat valley soils the slope may not give a steeper grade than 1 inch to 100 feet, while on steep slopes the furrows may be on much steeper grades. The proper grade depends much on the character of the soil. On an average sandy loam a flat grade of 3 to 6 inches in 100 feet is preferable. On steep hillsides flat grades for the furrows can be obtained by setting out the trees or crops so that the furrows will run across the slope. Some soils that do not wash easily are irrigated successfully with slopes as steep as 10 or 12 feet in 100 feet; but generally such grades are excessive and require that very small streams be turned into the furrows and great care be taken to prevent washing of the soil.

The spacing of the furrows will depend on the crop. For orchard irrigation, the number of furrows between tree rows varies with the opinion and judgment of the irrigator. For young orchards frequently only two furrows are used for each row of trees, one on each side of the trees. For older orchards at least three furrows are used, one on each side of the trees and one in the center between tree rows. To obtain a more uniform distribution of moisture, as many as six or eight furrows between tree rows are used. The present tendency is to use deeper furrows and space them farther apart. A depth of 8 inches is frequently used. The orchards in southern California are usually furrowed with plows attached to the frames of wheeled cultivators in the place of the cultivator teeth; this will give furrows 8 to 9 inches deep with a bottom width of 10 inches and a top width of 15 inches, Plate II, Fig. D.

The experiments on percolation of water from furrows, previously described, give results which should guide the orchardist in adopting the best arrangement of furrows. These experiments

showed that for a sandy soil with furrows 4 feet apart, it required about 24 hours for the water to spread sideways and meet between furrows; for a clay loam about 12 hours was sufficient. The sideways spread was greater for a deep furrow than for a shallow furrow. With deep furrows the sideways spread was limited to about 2 feet on each side of the furrow for sandy loam and about 3 feet for clay loam; this would indicate that the distance apart of furrows should not be over 4 feet for sandy loam and 6 feet for

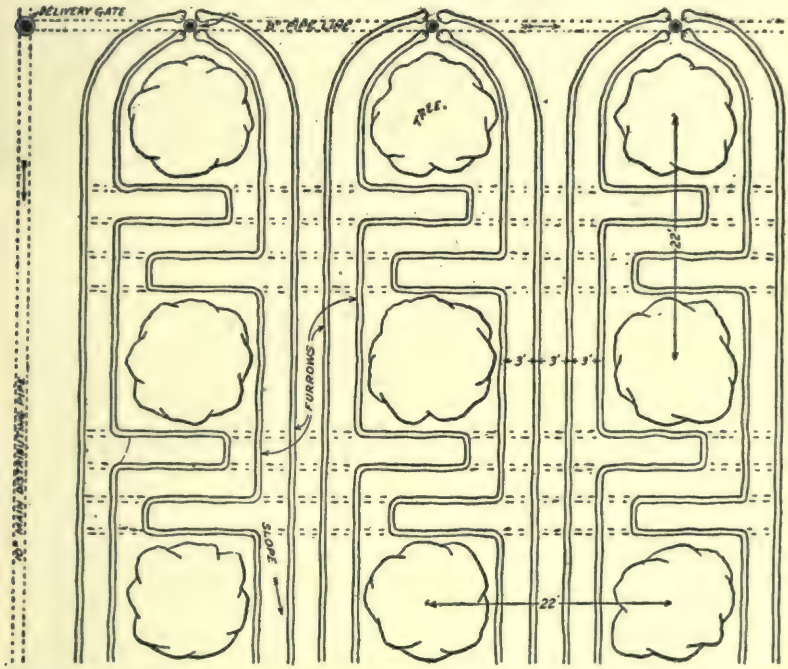

FIG. 36.—Plan for laying out zigzag furrows from cement pipe distribution system. From O. E. S. Bull. 236, U. S. Dept. of Agriculture.

clay loam. The furrows on either side of the row of trees should be placed as near as possible to the tree to moisten the soil directly under the tree. Usually the furrows are made parallel to the rows of trees. As the trees grow older, it is not possible to get the furrows sufficiently near the trunk; this leaves a space between the two furrows nearest to the trees, which is only partly wetted. To wet the soil more uniformly, the land is cross furrowed, so as to form zigzag furrows around the trees, as shown

by the accompanying sketch, Fig. 36. The furrows indicated by the dotted lines are first made, then crossed at right angles, and the necessary cuts and fills made with a shovel. Because of the greater length, slower velocity, and larger area wetted, thus obtained, a larger stream of water must be turned into them. Frequently only the lower half, third or fourth of the furrows is zigzagged, in order to give the lower part of the orchard as much water as the upper part, which otherwise receives a greater quantity.

Potatoes are irrigated by furrows made midway between the rows. The rows are spaced 36 to 42 inches apart. The furrows are made by a double mouldboard plow which forms a V-trench, with the bottom 6 to 12 inches below the crown of the plant. A common practice in Colorado is to open alternate furrows for the first irrigation, and for the next irrigation open the furrows in the

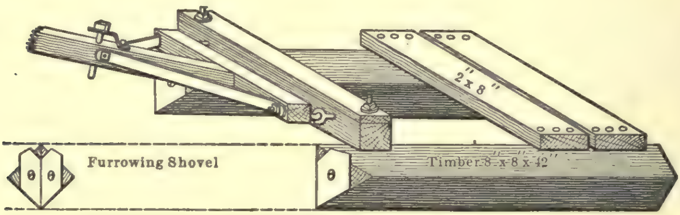

FIG. 37.—Furrowing sled. From Farmers' Bull. 392, U. S. Dept. of Agriculture.

intervals between rows which were left unopened in the first irrigation. For more than two irrigations the alternation is repeated.

Sugar beets, which are to be irrigated by furrows, are seeded by means of a drill with furrowing attachment which marks the rows 18 to 20 inches apart. The furrows are made either with a furrowing sled or preferably with a cultivator, to which are connected furrowing shovels. The furrowing sled, Fig. 37, can be made of two runners of 8 by 8 inch timbers, 42 inches long set on edge, connected together at the top by a platform of two cross pieces, 2 by 8 inches, nailed to the rear end, and by a 4 by 4 inch cross piece bolted to the front end, to which the draft is attached. The front end of the runner is sharpened to a V-point and shod with a furrowing shovel. In some cases three or more runners are used.

FIG. A.—Furrow irrigation of land newly seeded to alfalfa in Idaho.

FIG. B.—Furrow irrigation from concrete head flume.

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FIG. C.—Line of distributing stand pipes for distribution of water from cement pipe.

FIG. D.—Distribution of water in furrows from stand pipe.

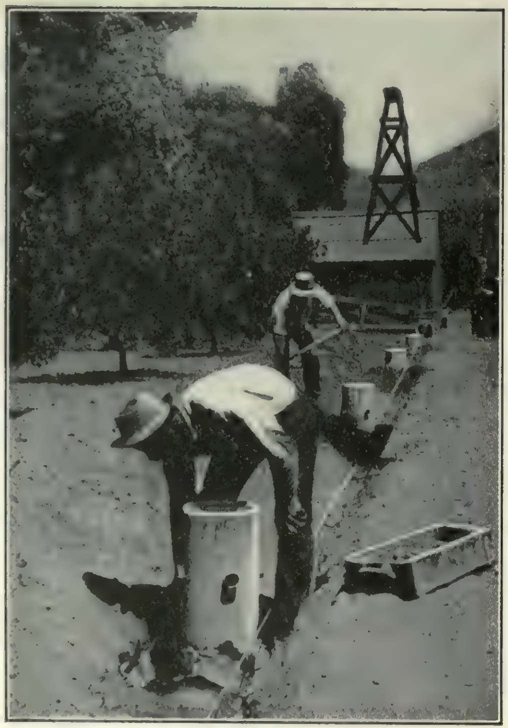

Fig. A.—Construction of distributing stand pipes.

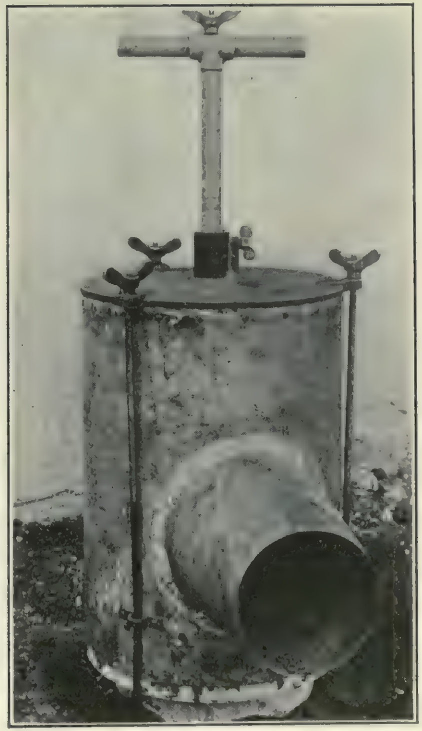

Fig. B.—Portable hydrant for surface pipe system of alfalfa irrigation.

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Plate IV

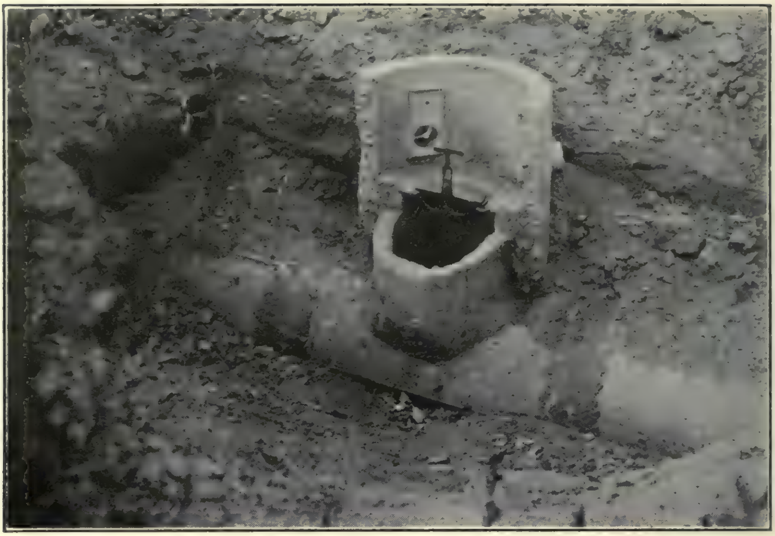

Fig. C.—Distributing pressure stand pipe, with valve.

Fig. D.—Surface pipe method of alfalfa irrigation.

The application of water by running the water in alternate furrows is practised in some localities. Investigations made by the Irrigation Investigations of the U.S. Department of Agriculture show that the yields were over 20 per cent. greater when water was run in every furrow.

Alfalfa and grain are irrigated to a considerable extent by the furrow method in eastern Washington, Oregon, and Idaho. With alfalfa, the method may be used when starting the young plants and be followed by the flooding method, Plate III. In the Yakima Valley of Washington, where the method is extensively used, it is known as the corrugation method. The water is run in shallow furrows, 3 to 6 inches deep, of about the same width, and spaced from 18 inches to 4 feet apart, depending on the character of the soil. The furrows are commonly made with the use of a marker or furrowing sled, which may be a rough implement made of logs fastened together and spaced the right distance apart, but preferably a furrowing sled as described above or one of the corrugators made by a number of manufacturers of farm machinery. The practice in the Yakima Valley is to make the furrows 18 inches apart when the land is first seeded to alfalfa and to abandon every other one after the plants are well rooted.

RUNNING WATER IN THE FURROWS

The heads delivered to the irrigator by irrigation companies may range from a few miner's inches to 200 or more miner's inches. For small orchards or farms, heads of from 1/2 cubic foot per second to 1 1/2 cubic feet per second, are desirable. For the citrus orchards of southern California, the heads delivered range from 30 to 60 miner's inches (50 miner's inches equal 1 cubic foot per second). A head of 30 miner's inches for 48 hours each month on a 10-acre tract, which is a common allotment at Riverside, California, will give a depth of irrigation of about 3 inches. The number of furrows into which the irrigating head may be divided will depend principally on the character of soil and the slope of the furrows. The stream turned into each furrow varies from 1/2 a miner's inch or less, to 3 or 4 miner's inches. On tight soils a small stream running slowly and for a long time, must be used to give time for the water to percolate into the ground without a waste at the lower end. On sandy soils, it is necessary

to use 3 or 4 miner's inches, in order that the water will reach the lower end of the furrow without an excessive amount being absorbed at the upper end. A good practice is to begin with a large stream into each furrow and rush the water to the lower end, then reduce the size of stream to obtain an even distribution.

The time the water is run into the furrows varies in general from 4 to 48 hours. The results of experiments on percolation from furrows, made in southern California, previously described, show the depth and lateral spread of water in the soil at different times for typical orchard loams. Prof. R. W. Fischer, of Montana, found that on the clay loams of the apple orchards on the east bench of the Bitter Root Valley, it requires 12 to 18 hours to moisten the soil in furrow irrigation, 4 feet deep and 2 feet sideways.

DISTRIBUTION OF WATER TO FURROWS

The water is delivered to the head of furrows through a system of earth ditches, flumes, or pipes. Where the orchard or field is

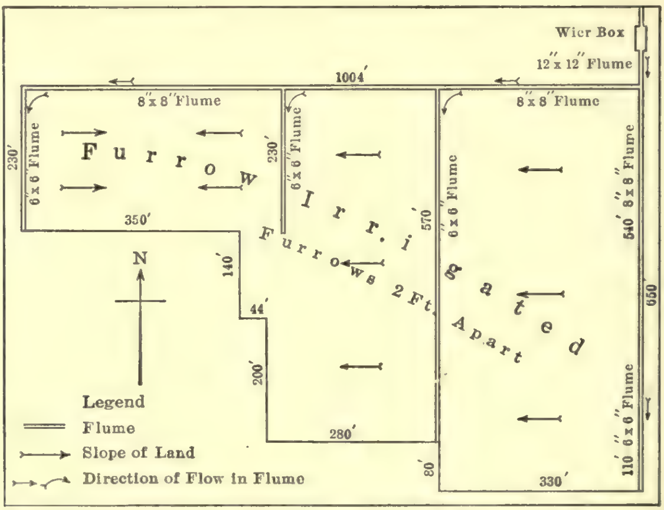

FIG. 38.—Distribution system for ten acre tract, Kenewick, Wash. From O. E. S. Bull. 188, U. S. Dept. of Agriculture.

small and the slope regular, one head ditch or head flume carrying the water from the point of delivery and placed on the highest part of the land to be irrigated, may be all that is necessary. For land

of uneven slopes, formed of ridges and depressions, the position of the ditches, flumes or pipes, will be on the ridges to serve the furrows on each side. For large tracts two or more head ditches, connected to supply lines, are necessary. In laying out such a distribution system, the irrigator should study the topography of the land and subdivide the orchard or field with a system of distributaries which will give furrows of proper length and on a good slope. A typical wooden flume distribution system for an alfalfa field is shown in the accompanying diagram, Fig. 38.

The success in obtaining uniform distribution of water depends largely on the method used to divide the water equally between the furrows. The earliest method of carrying the water to the

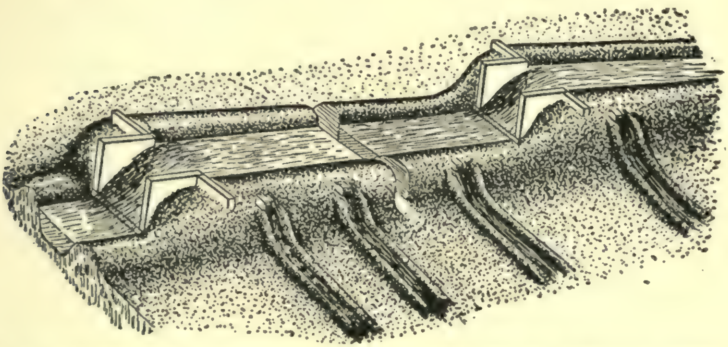

Fig. 39.—Method of placing lath tube in ditch bank for furrow irrigation. From Farmers' Bull. 373, U. S. Dept. of Agriculture.

head of the furrows is by means of the earthen head ditch located at the upper end of the furrows. The division of the water is effected by cuts made in the side of the ditch. This method is still used by many, but because crude and unsatisfactory, it has led to improvements, such as the placing of lath tubes or iron spouts in the ditch bank, Fig. 39, or to replacement by wooden flume, concrete flume, or pipe distribution systems. The importance of equal division of water in the furrows is illustrated by the results obtained from experiments made in Colorado on the irrigation of sugar beets. When the water was distributed to the furrows through spouts placed in the ditch bank, the yield was about 20 per cent. greater than when distributed through cuts in the top of the bank.

EARTHEN HEAD DITCH

To turn the water from the earthen head ditch into the furrows through the opening in the bank, the flow down the ditch is checked and the water level raised by placing in the ditch dams of canvas or metal tapoons, or by making dams of earth or manure. When the ditch is permanent, a wooden or concrete check gate can be built in place. The greatest difficulty in irrigating from an earthen head ditch is the care necessary to give a satisfactory division of the water in the furrows. A skilled irrigator may adjust the size of openings made in the ditch bank, so as to secure a fairly uniform flow in the furrows, but it requires

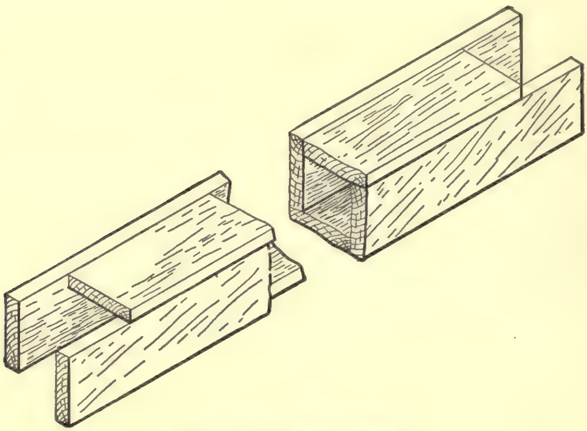

Fig. 40.—Lath tube.

attention to prevent the unequal washing of the soil at some of the openings, and this will cause greater discharges through some openings and lower the water level so that other furrows will receive little or no water. To prevent this unequal washing, pieces of sacks or canvas, pieces of shingles, small rocks, etc., are sometimes used; a better device is the use of short tubes placed in the bank of the head ditch. These tubes may be made of laths cut in 2-foot lengths and nailed together, Fig. 40. or may be pieces of discarded pipes 1/2 inch to 2 inches in diameter. A lath tube having an inside opening 1 inch square placed 4 to 6 inches below the water level will give a discharge of about 1 miner's inch. The flow through the tube can be regulated by a slide. The surface of the water can be kept at the proper height by means

of check gates and spaced according to the grade of the ditch. The accompanying sketches show the lath tube and the manner of placing them, and also the check gates in the ditch bank.

WOODEN HEAD FLUMES

Wooden flumes with small openings in one side give more accurate division of the water and are used very extensively. They can also be elevated above the ground to carry water over shallow depressions, which is an advantage over earthen ditches. However, the height above the ground must not be over 2 or 3 feet, or the water falling through the opening into the furrows will

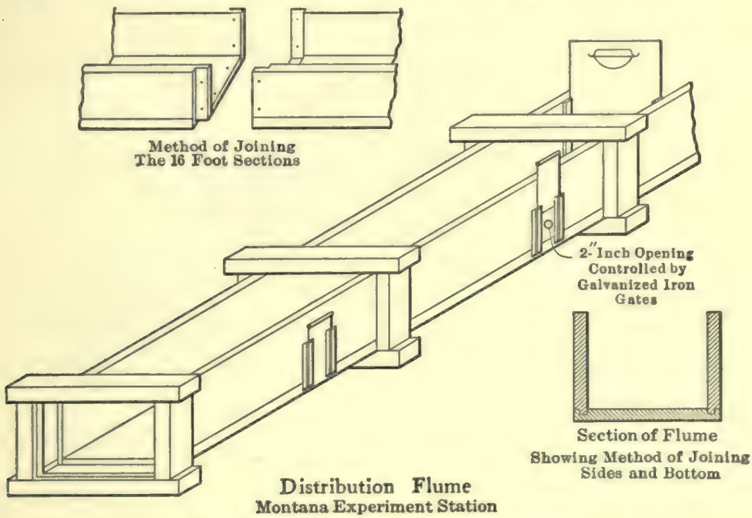

FIG. 41.—Head flume for furrow irrigation.

cause excessive washing. The flumes usually vary in width from 8 to 12 inches and from 6 to 10 inches in height, and the openings are controlled by metal or wooden slides, Fig. 41.

CONCRETE HEAD FLUMES

The short life of wooden flumes has led most of the orchardists of southern California to use either concrete flumes or cement pipes. A concrete head flume, Plate III, Fig. B, is made of the same form as a wooden flume, and galvanized iron spouts or tubes from 3/4 to 1 1/2 inch in diameter are inserted in the side of the flume before the concrete has hardened, there being

one spout for each furrow, Fig. 42. On steep slopes where the velocity is high, to give an even distribution through the spouts, checks made of short pieces of lath are inserted below each opening as shown in the accompanying sketch. To hold the checks in place, one end of the lath fits into a groove cut in the side of the flume by means of a trowel, before the concrete is hard.

The thickness of the floor for all sizes up to 24 inches in width is 2 inches. The side walls for all depths up to 12 inches are 2 1/2 inches thick at the top and 3 inches at the bottom. The

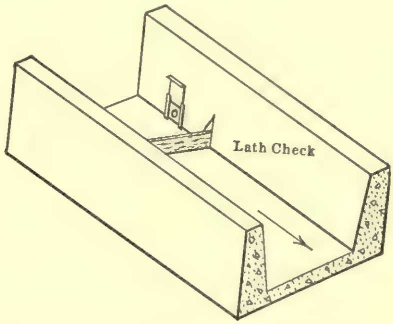

FIG. 42.—Concrete distributing flume.

flumes are made almost any size. The dimensions and cost of some of the sizes commonly used in southern California are as follows:

Depth, inches	Bottom width, inches	Cubic feet of concrete per lineal foot of flume	Cost per lineal foot in cents
8	11	0.54	20
9	12	0.60	22
10	12	0.63	24
10	14	0.66	25
10	16	0.69	26
10	18	0.71	27
10	20	0.74	28
10	22	0.77	28½
10	24	0.80	29
12	12	0.71	25
12	14	0.74	26
12	16	0.76	27
12	18	0.79	28
12	20	0.82	29
12	22	0.85	29½
12	24	0.88	30

The flumes are constructed on the ground by using a set of forms or moulds into which the concrete is placed. The moulds, Fig. 43, consist of an inside bottomless trough made of the same dimensions as the inside of the flume, and outside walls or sheathing held the proper distance apart from the inside form by means of spacing blocks and heavy U-shaped iron, straddling over the outside wall and inside wall. Instead of the U-shaped iron, the outside walls could be held in place by stakes driven in the ground. To build the floor and sides at the same time, the inside walls are held above the ground by the spacing frames a height equal to the thickness of the floor. The flume is built in sections 12

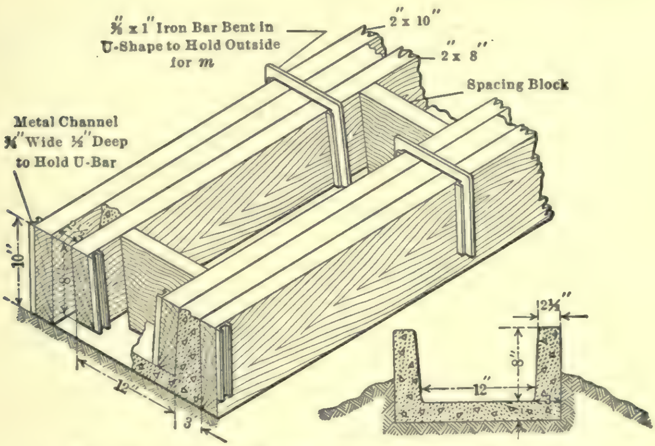

FIG. 43.—Forms for construction of concrete flumes.

feet long, which is the length of the forms. No provision is made for contraction and small shrinkage cracks occur. These could be eliminated by inserting at the edges a metal tongue 2 or 3 inches wide imbedded about halfway into each section. This tongue should be well painted with oil or soap to prevent the adhesion of the concrete, and it will then act as a tongue and groove joint.

To permit the quick removal of the forms, which is necessary unless sufficient forms are used to build a considerable length at one setting, the concrete is mixed comparatively dry and requires careful tamping. A mixture of 1 part of cement to 5 of well-graded pit gravel is generally used. It is important that

the concrete be kept moist by sprinkling or otherwise, for a period of at least one week. When completed, the side walls are partly backfilled with earth up to about one-half of their height. It is better to have the spouts at least 4 inches long, and preferably 6, to prevent the washing away, by the action of the water coming out of the spout, of the soil from under the flume, which will cause it to settle and crack. These galvanized iron spouts are made by local metal workers at a cost of 4 3/4 to 5 1/4 cents each.

CEMENT PIPES AND DISTRIBUTING STAND PIPES

In southern California many hundreds of miles of cement pipes have been used for the distribution of water to orchards, and in recent years its use has been extended to some of the orchards in Washington and Idaho. While many orchardists in southern California still prefer the open flume, there are the following objections to open flumes:

First.—Teams and farm implements cannot cross the flume, and there is always a strip of land on each side that can only be partially cultivated because it cannot be crossed in the opposite direction.

Second.—The flume is liable to be damaged by the teams and farm implements.

Third.—The flume may settle and crack if the earth underneath is washed away by the water passing through the spouts into the furrows.

Fourth.—The furrows can only be made with teams and cultivators up to 15 feet from the flume, and they must be completed by hand.

Fifth.—Leaves may fall in the flume and stop up either partially or completely the openings of the distributing spouts, which requires extra time on the part of the irrigator.

These disadvantages have led many of the orchardists to the use of underground pipes which do not interfere with cultivation.

A complete underground pipe distributing system consists of:

First.—A main pipe line which carries the water from the measuring box or point of delivery to the lines of distributing stands, which take the place of head ditches.

Second.—The distributing lines which conduct the water from

the main pipe line, and which are connected to the distributing stands.

Third.—The distributing stands or basins by means of which the water is brought to the surface and distributed into the furrows through small galvanized iron spouts inserted in the sides of the basin.

Fourth.—Regulating boxes and accessories.

A typical system is shown in the accompanying sketch, Fig. 44. The pipe lines are made of hand-tamped pipe placed in trenches of such depth that there is at least 1 foot of earth covering.

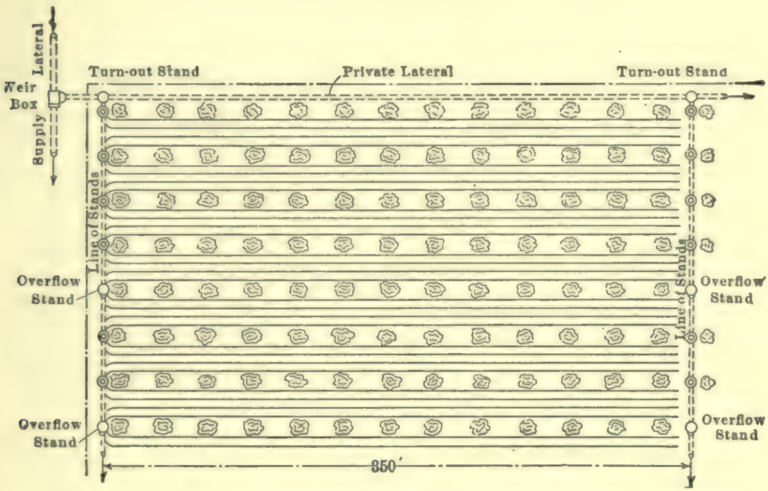

Fig. 44.—Cement pipe system of distribution for orchard furrow irrigation.

The properties of the pipe and the cost of making and laying are given in the next chapter. The main pipe line or feed line is not necessary where only one line of stands is necessary, such as where the orchard is small and can be irrigated with one set of furrows 330 or 660 feet long. But for larger orchards it is desirable that the orchard be supplied by two or more head ditches or distributing pipe lines in order to limit the length of the furrows to not over 660 feet and preferably 330 feet for sandy soil. The main supply pipe feeds the distributing lines and conducts the water from the measuring box or point of delivery to the head of the line of stands. At the junction of the line

of stands with the main pipe, turnout boxes with suitable gates are necessary to control the flow into each line. The lines of

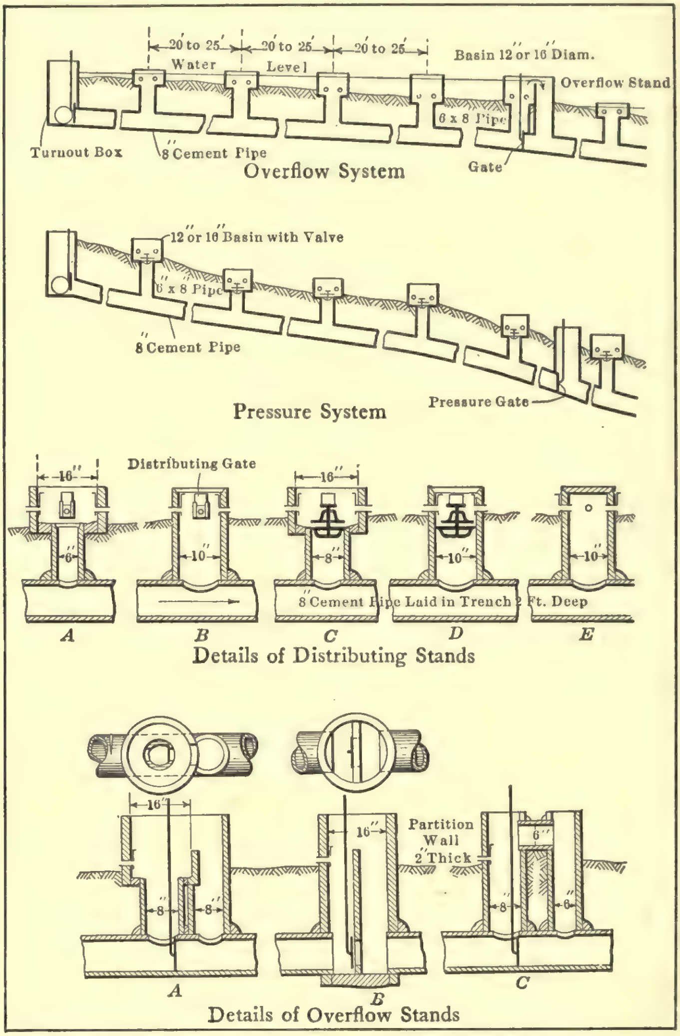

FIG. 45.—Details of cement pipe distributing lines.

distributing stands extend across the direction of the furrows. At the head of each tree row and in line with the trees a distributing stand is connected to the distributing line, Plate III,

Fig. C. In walnut orchards where the trees are spaced 40 to 60 feet apart an intermediate stand is often used, Plate III, Fig. D.

There are various ways of making the stands and of regulating the flow. They vary only in details and can be classified into two distinct systems, one known as the overflow system, and the other, the pressure system.

The overflow system is best adapted where the line of stands is placed on a flat uniform grade. The pressure system is best where the slope of the ground is steep and not uniform. These two systems are illustrated in the accompanying diagram, Fig. 45. With the overflow system, the lines of stands must usually be divided by means of overflow boxes or pressure regulating boxes into a number of sections, depending on the grade, and each section includes a number of distributing stands, the tops of which are placed at the same level. The overflow box acts as a check in a head ditch, and by closing or regulating the gate of the overflow it causes the water to rise in the distributing stand and maintains the water surface in the stands at about a uniform level. If the gate of the overflow box is closed, the water which is not distributed through the stands above it, passes over the overflow to supply the stands below; this makes the system practically automatic. The distributing stands are seldom made higher than 16 inches above the ground; when it exceeds this, a new section or group of stands is made by inserting another overflow box. On steep grade the cost is much increased because of the great number of overflows.

The pressure system, or valve system, is so called because the distributing line is divided into a number of sections, depending on the grade, so that each section is under a water pressure which the pipe will safely stand. Because of the pressure, it is necessary to regulate the flow into each basin by means of a valve. Usually the sections should not be longer than 600 feet and the pressure head should not exceed 15 feet. The boxes which divide the line in sections control the pressure by means of a gate. The diagram shows the position of this gate, which is placed on the upstream or inlet side of the box. The pressure of the water tends to push the gate away from the gate frame, and causes leakage. To prevent this, the gates, which are named pressure gates to distinguish them from the cheaper slide gates, are so designed that when the gate is closed, turning the handle brings the gate tight against

its frame. This is obtained through some mechanical device, which varies in construction with the different manufacturers. Instead of using pressure gates, the ordinary slide gate can be used by placing it on the downstream side or outlet to the box, but in this case the box must be built so that its top is higher than the highest distributing stand of the section, Fig. 46. This may require a height of 10 or 15 feet above the ground, which is objectionable. The pressure system can be used where the distributing line has to cross shallow depressions. In all cases the line must be divided into sections, so that the maximum head will not exceed 15 feet.

DETAILS OF STANDS

The stands are shown in detail in the accompanying diagram, Figs. 45 and 46. Stand A, used for the overflow system, consists

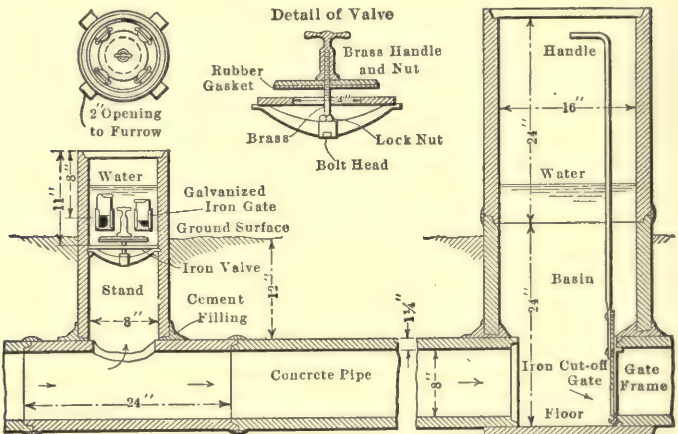

FIG. 46.—Details of distribution stand pipe and check stand pipe.

of a section of 6- or 8-inch pipe, placed vertically with the lower end cut to saddle over a 6- or 8-inch hole made in the pipe line by means of a sharp pick. The joint is made with a rich cement mortar mixed in the proportion of 1 part of cement to 2 of sand. Around the upper end of the pipe, at the surface of the ground, is placed the distributing basin, and the space in the basin around the smaller pipe is filled with cement mortar. The basin is usually a section 6 to 18 inches long of 16-inch pipe. Around

the circumference of the basin, near the floor, from four to six distributing gates or spouts are inserted and cemented in holes, cut as soon as the basin has been made or cast in the basin when making it in the metal moulds.

Stand *B* is also used for the overflow system, and consists of a single length of pipe 8 to 12 inches in diameter in which the spouts are inserted, Plate IV, Fig. A. The larger basins of the type A are preferable where the furrows tend to wash together.

Stands *C* and *D* are used for the pressure system. They are made as stands *A* and *B* with the addition of the regulating valve cemented in the upright pipe, Plate IV, Fig. C. Stand *E* can be used also for the pressure system. It is similar to basin *B* with the top closed by a cap of cement mortar. This stand requires that spouts be opened from the outside, and unless they are properly made, the pressure will cause them to leak. With the other stands, the spouts may open either from the outside or inside.

Overflow Stands.—Overflow *A* is ordinarily made of a section of 16-inch pipe, at the top of which is cut an overflow notch 5 or 6 inches deep and 7 inches wide, and against this 16-inch pipe and cemented to it is a semi-circular or 2–3 circular section of an 8-inch pipe. The gate in the upstream compartment is a simple slide gate.

Overflow *B* consists of an overflow wall 2 inches thick, built in a 14 or 16-inch pipe. Overflow *C* is made of two standpipes connected with a short piece of 6-inch pipe.

Draining the Pipes.—In order to empty the pipe to prevent bursting by freezing and also to flush out any silt, it is necessary that at all the lowest points openings controlled by valves or gates be provided.

Accessories.—The accessories needed for a pipe system are: (1) the galvanized iron spouts, (2) regulating gates, which are either the simple cast-iron or steel slide gates or the pressure gates, (3) the valves. These devices are made by several manufacturers in southern California, varying only in the details, and are sold for the following approximate prices:

COST OF GALVANZIED IRON DISTRIBUTING GATES

Diameter	Price for light weight	Price for heavy weight
1 inch	4 3/4 cents	7 cents
1 1/4 inch	5 cents	.....
1 1/2 inch	5 1/4 cents	10 cents

COST OF VALVES

Number of valve	Size of opening	Price
5	2 1/2 inches	$0.70
6	2 1/2 inches	0.75
8	5 inches	0.85
10	6 inches	1.10
12	8 inches	1.80
14	10 inches	2.75

COST OF GATES

Size of opening	Cast iron slide gates	Cast iron pressure gates
6	$1.60	$3.40
8	1.75	3.85
10	2.50	4.60
12	3.60	5.90
14	4.60	7.85
16	5.70	10.25
18	8.20	12.50

APPROXIMATE COST OF STANDS IN PLACE

Type of stand	Price complete
A	$1.00 to $1.50
B	0.90 to 1.25
C	1.75 to 2.00
D	1.65
Overflow	2.75 + slide gate

PRESSURE PIPE LINES AND VALVES

On some of the orchards in British Columbia, Idaho, Washington and southern California, the water is distributed over the orchards in high-pressure, wood-banded pipe lines. The pipe lines take the place of the head ditches; they are tapped at each row or wherever desired by a standpipe, formed by screwing in the wood short sections of galvanized iron pipe capped by an ordinary garden valve to regulate the flow. Where the land is very irregular and it is desired to keep the water under pressure, this form of construction is the most desirable and in fact the only feasible one; but if it is possible to break the pressure and maintain it within the safe pressures for cement pipes by proper regulation, the cement-pipe distributing system has the advantages of lowest cost, greater durability and better division of the water between furrows.

SURFACE PIPE METHOD OF IRRIGATION

This method is extensively used in southern California for the irrigation of alfalfa by flooding, and to a less extent for the irrigation of orchards or other crops by delivering the water into checks or basins. The method consists in distributing the water on the land through canvas hose or metal pipes, made of detachable lengths, placed on the surface and moved from one section of the field to another until the entire field is covered, Plate IV,

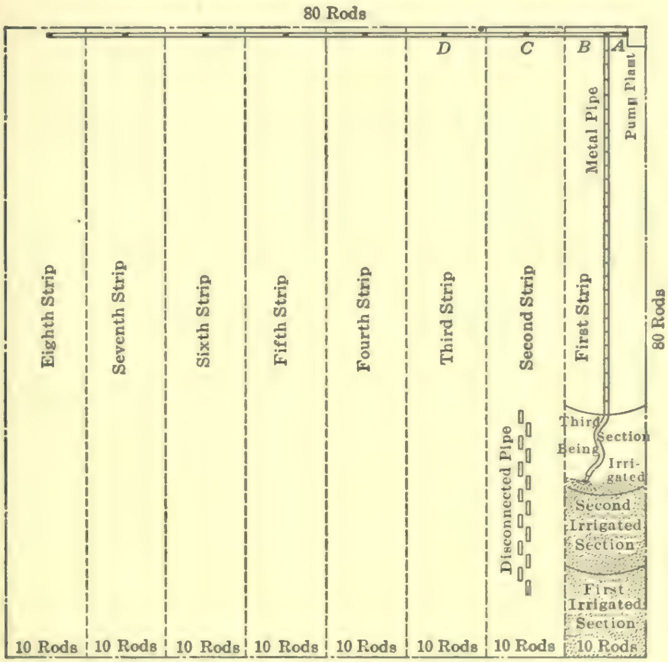

FIG. 47.—The use of slip-joint pipe in applying water to land. From Farmers' Bull. 392, U. S. Dept. of Agriculture.

Fig. D. It is possible to apply the water on land which is slightly uneven, without previous preparation of the surface, by forcing the water through the pipe to the higher points, but to obtain uniform distribution of water without accumulation in the low spots, good practice requires that the land be smoothed to obtain an even surface. The method is best adapted to small heads of water which cannot be conveyed in earth ditches without ex-

cessive seepage loss and which cannot be applied to the land by the ordinary methods of flooding without a large loss by deep percolation. It requires a good grade or a pressure in the pipes to deliver a sufficient head of water without excessively large pipes. It is more expensive in first cost and in labor than the other methods of flooding; but is economical where the value of water is high, such as when the water is developed by pumping.

To supply the surface pipes, a system of underground pipes carries the water from the point of delivery to the irrigator, or from the pumping plant to points on the underground pipes,

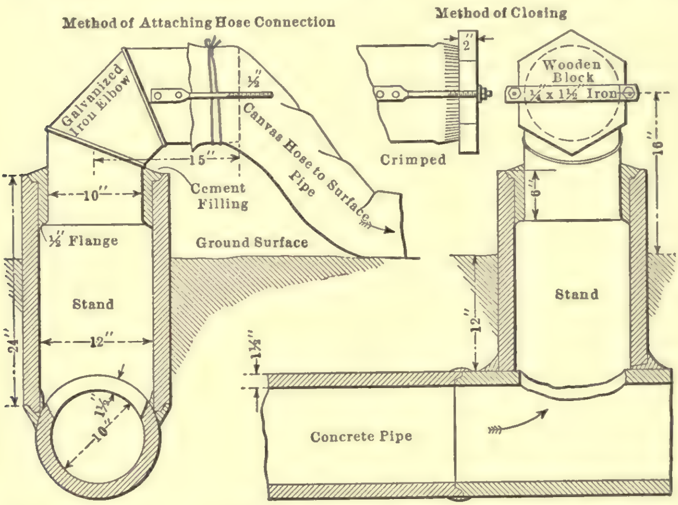

Fig. 48.—Design of concrete stand for alfalfa irrigation by slip-joint surface pipe. From O. E. S. Bull. 236, U. S. Dept. of Agriculture.

which are tapped with a standpipe to give a connection to the surface pipe. The underground pipes correspond to the pipes used for furrow irrigation, described above; for this, cement pipes are commonly used; vitrified clay pipes are preferred by some, but are generally more expensive; steel pipes are used when the pressure is too large for cement or clay pipes.

For tracts not larger than 40 acres or for tracts where the width does not exceed 1/4 mile one underground head line with standpipes about 100 to 160 feet apart, placed along the higher boundary or on the ridge of the field is sufficient, Fig. 47. For larger tracts, it may be necessary to divide the field into

sections by two or more head lines, connected by supply pipes. The size of the head lines and supply pipes is controlled by the carrying capacity and the available grade or pressure. The standpipe, Fig. 48, which connects the underground head pipes to the surface pipe, is commonly made of a section of cement pipe, placed vertically with its lower end cemented to the underground pipe over a hole cut in this pipe, and with a galvanized iron elbow cemented to the upper end. Another form of stand-

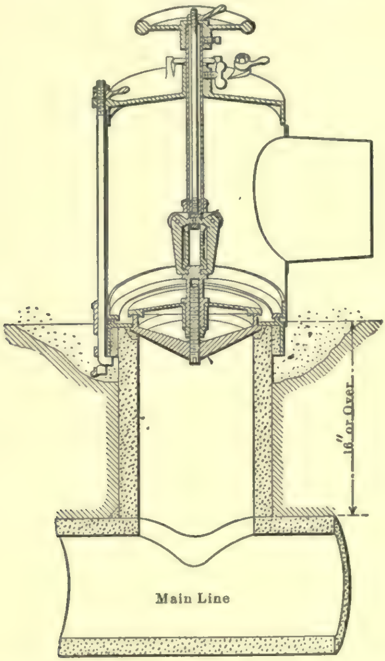

Fig. 49.—Cross-section of stand pipe, alfalfa valve and portable hydrant.

pipe is obtained by cementing to the upper end a valve similar to the valves used in orchard head lines, and making the connection between the stand pipe and the surface pipe with a portable hydrant box which clamps around the upper end of the standpipe, Plate IV, Fig. B. The portable hydrant box has a socket wrench, which grips the nut on the valve lid, thus regulating the flow, and has a large spout to which the surface pipe is connected, Fig. 49. For steel pipes, the stand pipes consist of large valves with spouts.

The surface pipe is generally galvanized iron pipe, made in short detachable lengths. Canvas hose was formerly used to a considerable extent, but because of its short life is considered inferior to the iron pipe, and its use is now very limited. A short length of canvas hose is frequently used to connect the upper end of the first section of iron pipe with the stand on the head line. The hose is 1 inch greater in diameter than the iron pipe; one end is tied to the stand and the other end is placed in the pipe, which it fits when expanded by the water. The canvas hose is made of 10- or 12-ounce duck and will stand only a small pressure; the life is from 1 1/2 to 2 seasons for the plain hose and from 2 to 2 1/2 seasons for hose treated with a preparation. The surface iron pipe is made from 4 to 12 inches in diameter of No. 20, 22, or 24 galvanized iron. The heavier pipe is more durable, but more costly and more difficult to handle. The length most commonly used is 10 feet, and is preferable to handle than longer lengths of 12 or 16 feet. The best pipe is made of one sheet of metal, with the longitudinal joint made by riveting and soldering or by a lock seam and soldering. The taper end, about 8 inches long, is made of heavier metal, No. 16 gauge; the bell end is reinforced with a band of No. 16 gauge.

The usual procedure in distributing the water is to connect to the outlet of the stand pipe or to the outlet end of the canvas hose the first section of metal pipe, then connect succeeding sections of pipe, while the water is flowing through it, until the lower end of the strip served by the pipe line is irrigated. The pipe is then disconnected at the upper end and irrigation of the next strip is carried on in the same way. Where the distance between stands is larger than the width of strip which can be irrigated from one position of the pipe line, then two or more locations of the pipe line must be served from one stand by shifting the position of the connecting canvas hose. This method is preferable to that of connecting the entire line of pipe by starting at the lower end and working up by taking off lengths, because of the difficulty in disconnecting the sections when they are full of water, as the weight of a single section will then be several hundred pounds.

The size of the metal pipe will depend on the head of water used, the available grade, or the grade which can be obtained by producing pressure at the upper end of the pipe. A desirable head is from 1 to 2 cubic feet per second; with a head

of 2 cubic feet per second, one man can irrigate 4 acres 6 inches deep in 12 hours; with pipe sections of 10 feet, the distance travelled to move the pipe from one position to the other is about 1 2/3 miles per acre, or 6 2/3 miles for the 4 acres. With heads greater than 2 cubic feet per second, the connection and disconnection of the pipe must be so rapid to keep up with the spreading of the water that the labor is too much for one man. Pipes greater than 12 inches in diameter must be made heavier to stand the wear and are not handled with ease.

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CHAPTER VII

FARM DITCHES AND STRUCTURES FOR THE DISTRIBUTION OF IRRIGATION WATER

GENERAL DESCRIPTION

The water supply for an irrigated farm is obtained usually from one of the laterals of the irrigation system, which commands a number of farms or a large area of land. It may also be obtained from a pumping plant and in a few cases directly from a natural water course. When the water supply is obtained from a lateral of an irrigation system, the water is delivered to the farm through a delivery gate, which may serve also as a measuring gate or which may be combined with a separate measuring device. When the water supply is developed by pumping, the water is delivered either in a receiving box, which may be a measuring box, or in a storage tank, or discharged directly in the main ditch or conduit of the distribution system.

The delivery gates and measuring devices are usually constructed as part of the main irrigation system, and will be considered as pertaining to the system. Their design and construction as well as the methods of measurements will therefore be discussed in Volume III.

The distribution system of an irrigated farm includes the system of ditches or conduits required to convey the water from the point of delivery to the different parts of the farm, and of the farm structures required to regulate, divide and distribute the water to the land. The character of the distribution system will depend largely on the area of the farm, the topography, the method of irrigation and the value of the water. Where the area is a large farm of several hundred acres, the distribution system may include a number of laterals and structures similar in design to those forming part of a general irrigation system. The topography of the land will control to a considerable extent the method of irrigation, which is an important factor in determining the location and the capacity of the distribution sys-

tem. The value of the water will determine the economy with which water should be used and is a factor in selecting the type of construction.

The farm ditches and conduits may be divided into those from which water is taken out and applied to the land, which are commonly called head ditches or head flumes, and those ditches or conduits which convey the water from the point of delivery to the head ditches and which may be called supply ditches, flumes or pipes. The head ditches may be temporary earth ditches, which are made before each irrigation or before each season of irrigation, such as for the wild field flooding method of irrigation and for the crude method of furrow irrigation, or they may be permanent earth ditches with permanent structures, such as for the check or border method of flood irrigation, which require ditches of larger capacity. For the furrow method of irrigation, head flumes of wood or concrete or head pipe lines with distributing stands may be used; these have been previously discussed and described in connection with the methods of application of water to the land.

The supply conduits are more liable to be permanent than the field distributaries—they may be earth ditches, or flumes of wood or concrete or pipe lines.

The structures used on the distribution system consist of the structures used to regulate the flow in the supply and head ditches, such as checkgates, division gates, drops, and the structures to take out and distribute the water from the head ditches or conduit such as levee gates in the banks of the earth ditch to turn the water into the checks. On the larger ditches, farm bridges may also be necessary.

PLANNING AND LOCATION OF DISTRIBUTION SYSTEM

This requires first a careful study of the topographic conditions, the crops to be raised, the available head or stream of water, in order to determine the best method of irrigation. The system is then planned to fit the method of irrigation. For the wild flooding method, the direction in which the land is to be flooded is first selected, and the position of the field head ditches fixed accordingly. For the check method of flooding, the size and form of the checks is determined. For the border method, the

direction of flooding, the length and width of the borders must first be determined. For furrow irrigation, the direction and length of furrows must be fixed. After the position of the head ditches is determined, the supply ditches are planned and located to carry the water to the head ditches in the most feasible and economic way.

For small farms, a single head ditch, flume or pipe may be all that is required. Where the land surface of the farm has a continuous slope in one direction, not divided by ridges or depressions, the supply ditch will usually be along one of the

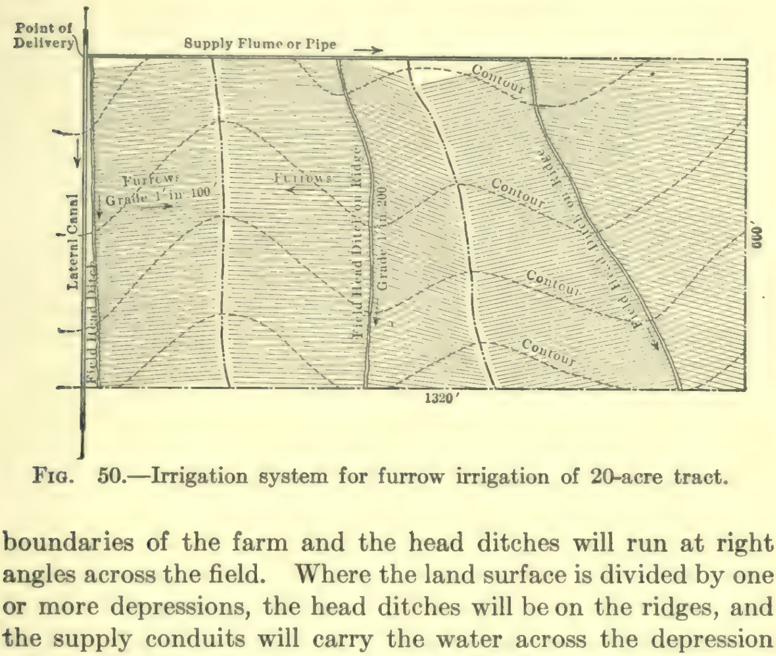

FIG. 50.—Irrigation system for furrow irrigation of 20-acre tract.

boundaries of the farm and the head ditches will run at right angles across the field. Where the land surface is divided by one or more depressions, the head ditches will be on the ridges, and the supply conduits will carry the water across the depression and will be either ditches in fill, flumes on trestles or pipes, Fig. 50.

REQUIRED CAPACITY OF FARM DISTRIBUTION SYSTEM

The capacity is determined from the irrigating head, which depends on the method of irrigation. The minimum head is that which will permit economic irrigation with least feasible loss of water by deep percolation and surface waste. Wild field flooding is usually practiced with a minimum irrigating head of about

1 cubic foot per second. Flooding by checks or by the border method requires a minimum head from about 1 second foot for small checks to 4 or 6 second feet for larger checks; this will, however, depend largely on the character of soil and in the case of border checks also on the slope. Furrow irrigation may be practised with small heads of very few miner's inches, but except for small farms of less than 5 or 10 acres, a minimum head of 20 miner's inches is desirable. The maximum supply head which may be used will depend on the volume of water which can be economically handled; a large head permits the application of water in a shorter time, which decreases the amount of labor involved, gives more time to the farmer for other farm operations, and will usually result in decrease in waste by deep percolation. The supply head may be divided so as to supply two or more head ditches at the same time; or the capacity of each head ditch may be made the same as that of the supply ditch to carry the entire supply head. In the field-flooding method of irrigation, the maximum supply head which can be handled by one man, is about 3 to 4 second feet. In the check method and border method of flood irrigation the standard supply head delivered in some large irrigation systems in the Sacramento and San Joaquin Valleys of California is 16 to 20 second feet; this is carried in the head ditches and turned into four or five checks or borders at the same time. In the furrow method of irrigation the supply head, which may be handled by one irrigator, is seldom larger than 1 to 1 1/2 second feet.

DESIGN AND CONSTRUCTION OF FARM DITCHES, FLUMES AND PIPES

The capacity of the farm ditches is determined from the required supply or irrigating head, as stated above. The design of the ditch to obtain the determined capacity depends on a number of factors, most important of which is the grade of the ditch, the velocity to be given, the form or shape of the ditch cross section, and the method of construction. These factors, as well as others, are considered in detail, especially from the standpoint of the engineer, in Volumes II and III. It is, however, desirable to present briefly in this chapter some of the principles of flow of water in ditches. The flow of water in ditches obeys the following laws:

First. The area of the water cross section in square feet multiplied by the velocity in feet per second gives the discharge in cubic feet per second.

Second. The velocity of water in a ditch increases with the grade. When all other conditions remain the same, including the same water area, the velocity and therefore the carrying capacity increases very nearly with the square root of the grade. For instance, if the grade is made four times greater, the velocity and carrying capacity are practically doubled.

Third. The velocity increases with an increase in the degree of smoothness of the sides and bottom of the channel in contact with the water. For instance, when all other conditions are the same, the velocity and capacity of a rough earth ditch, will be nearly half of that of a very smooth concrete-lined ditch.

Fourth. The velocity is affected to some extent by the form of the cross section of a ditch. The form which will give the least wetted surface or contact surface is the one which will more nearly approach a semi-circle. In practice, however, the farm ditches are usually made comparatively shallow and broad; this form is more easily constructed, and as ordinarily built by using the excavation to make the banks, it will carry a larger part of the volume of water above the original ground surface.

Fifth. In a given channel the velocity increases with an increase in the volume of water in the channel. For instance, a flume 3 feet wide carrying water to a depth of 1 foot with an average velocity of 2 feet per second, gives a discharge of 6 cubic feet per second. When it carries a depth of 2 feet, the area of the cross section is doubled and the velocity will be increased to about 2.55 feet per second, giving a discharge of 15.30 cubic feet per second, which is more than double the first amount.

FARM DITCHES

Farm ditches are not usually excavated and trimmed to trapezoidal sections as are the larger canals and laterals of an irrigation system. The form of farm ditches depends largely on the method of construction, which will vary with the size of the ditch. A farm ditch is usually built partly in cut and partly in fill, and when the ditch is placed sufficiently deep in cut to give enough excavation to make the banks, it is denoted as a balanced

cut and fill ditch. This is the cheapest type of construction, but it is not always feasible or desirable. When a ridge must be cut through, the ditch may have to be deep in cut with the water area all below the surface ground line; when a depression must be crossed, the ditch must be formed entirely in fill or some other form of construction used, such as a flume or a pipe. A balanced cut and fill section will usually hold the water level in the ditch above the ground surface; this is desirable in order to take the water out of the ditch and apply it to the land; to obtain this advantage to a greater degree, it is good practice, especially for the larger permanent ditches, to place the bottom of the ditch not so deep in cut and obtain the additional material to make the banks by scraping the earth from the adjacent land, preferably by removing the high parts and knolls.

The larger ditches, having a bottom width of about 3 feet or more, are usually constructed with Fresno scrapers, Plate V, Fig. A, worked back and forth across the ditch, removing the material which has been loosened by plowing a strip of land along the center line of the ditch. The banks are well compacted by the tramping of the teams. The ditch cross section has side slopes of about 1 1/2 to 1, to 2 to 1, with the bottom of the ditch and the crown of the bank rounded. Large ditches may also be constructed by the use of a suitable road grader, which for this purpose must have adjustments which will permit setting the blade to cut the desired side slope. The material is loosened by plowing and is scraped out, leaving smooth side slopes, but the banks are formed of loose material and are liable to break when the water level is above the original ground surface.

Ditch excavators, made by manufacturers of farm implements, and home-made ditchers are used to a limited extent only for large ditches. A device recently used with success in the Sacramento Valley, in California, consists of a large *V*-crowder, Plate V, Fig. B, similar to the smaller type used for small ditches, reinforced heavily with steel plates and strongly framed and pulled by two or three traction engines, Plate V, Fig. C.

Smaller ditches may be built by either using the ordinary lister or double mouldboard ditch plow, or by a home-made ditcher, such as used around Greeley, Colorado, formed of a right share and a left share steel beam plow, placed side by side and connected together with the shares spread to make a small ditch 18

FIG. A.—Constructing farm ditch with Fresno scraper, near Modesto, Calif.

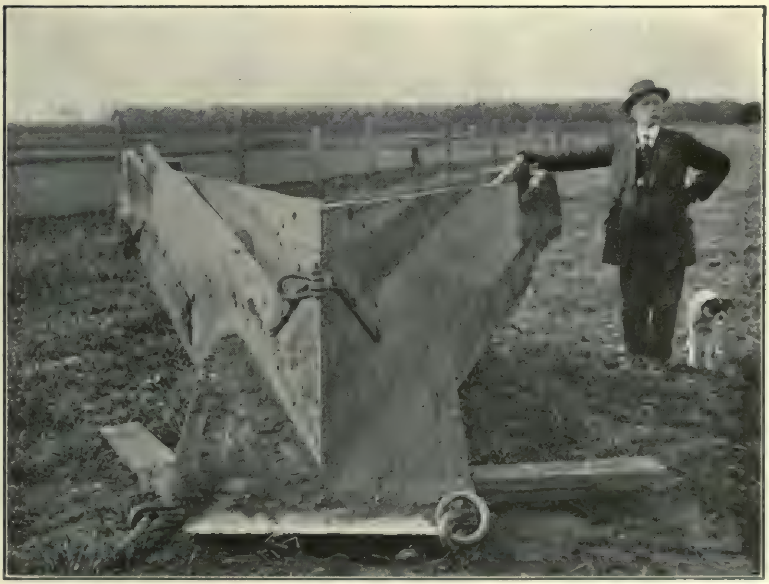

FIG. B.—Ditcher used near Woodland, Calif.

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Plate V

Fig. C.—Ditcher in use near Woodland, Calif.

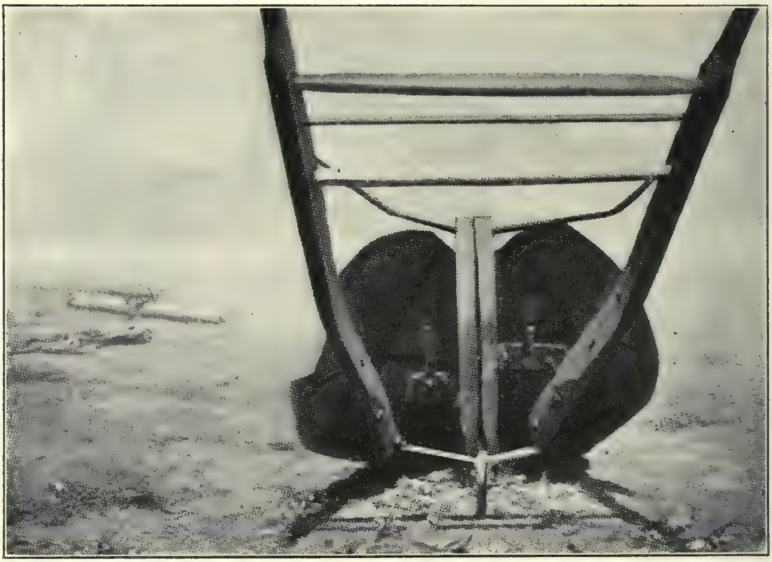

Fig. D.—Plow for making field ditches, made of right and left plows. From O. E. S. Bull. 145, U. S. Dept. of Agriculture.

inches or 2 feet on the bottom. The points at the rear end of the shares are cut off and the ends rounded; and above the mould-

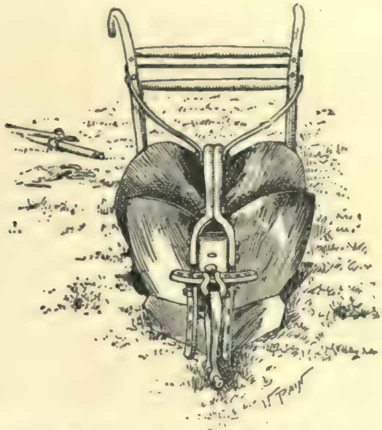

Fig. 51.—Plow for making field ditches, made of right and left plows. From U. S. Dept. of Agriculture Year Book 1903.

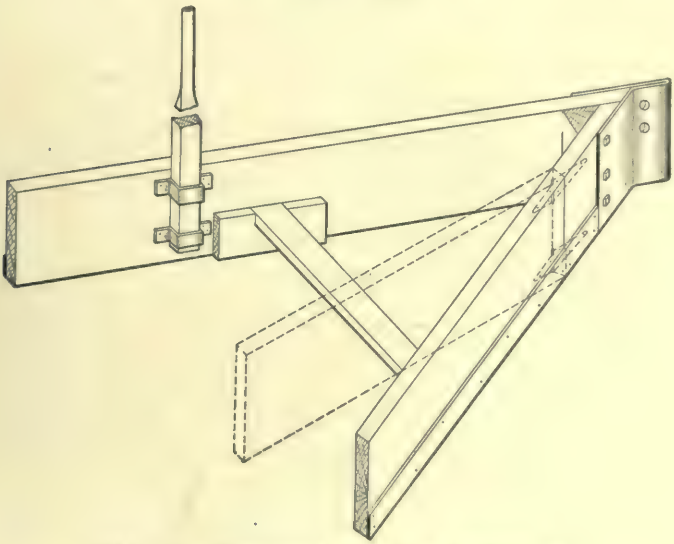

Fig. 52.—V-crowder for making field ditches.

boards of the plows and riveted to the upper edge of them are the right and left mouldboards of old alfalfa plows, Plate V, Fig. D,

Fig. 51. Another device very commonly used for small ditches is known as the *V*-crowder, Fig. 52. This device sometimes follows the lister or ditch plow described above, or may be used by first plowing two to four furrows on the line of the ditch, and then dragging the *V*-crowder up and back through the center of the plowed strip to throw the loose dirt up on the sides, Plate VI, Fig. A. These devices leave loose banks, which are easily broken

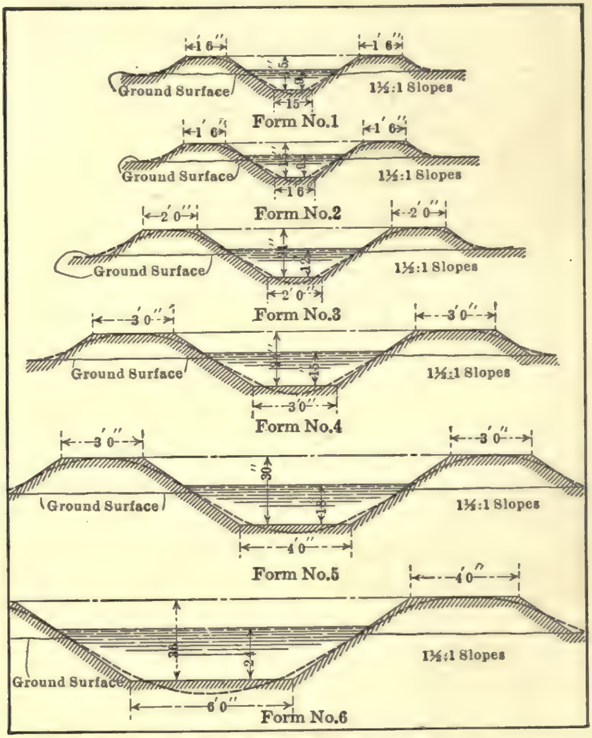

Fig. 53.—Typical section for farm ditches.

through when the water level is raised by checking; to compact the banks they are sometimes consolidated by dragging.

The *V*-crowder may be built either of wood or steel, and the width at the rear is usually made adjustable by a hinge joint toward the front end or apex of *V* and a variable spacer toward the rear end.

The ditches obtained with these devices are more or less

Fig. A.—Use of V-crowder in making field ditches. From Farmers' Bull. 404, U S. Dept. of Agriculture.

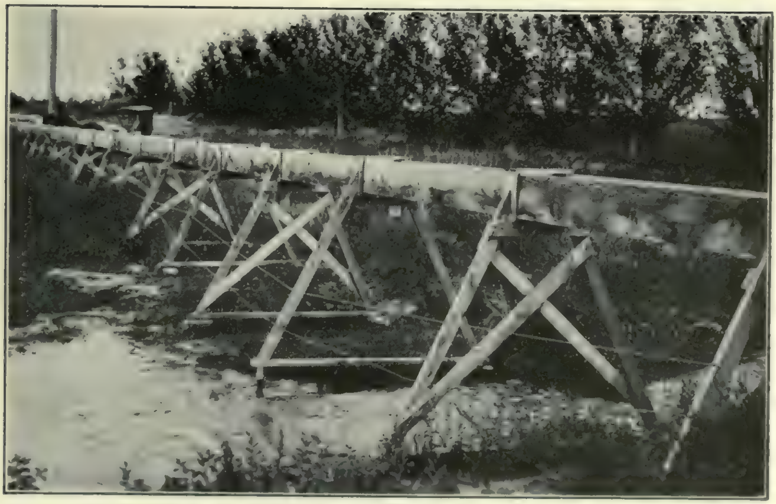

Fig. B.—Elevated farm flume in Idaho.

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PLATE VI

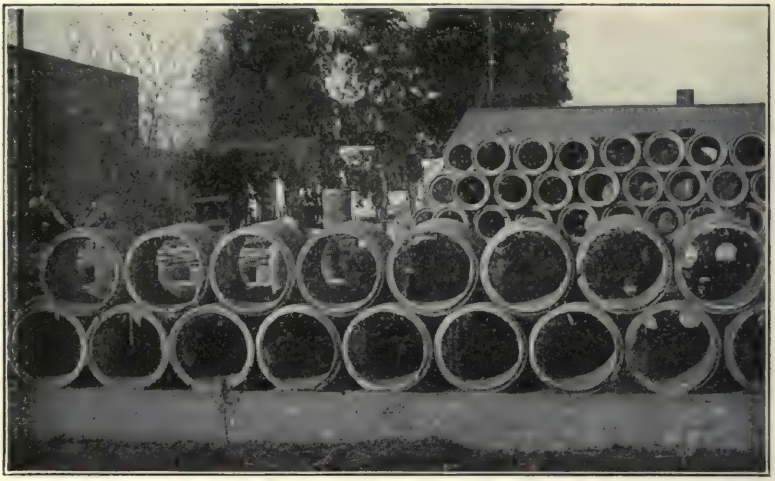


FIG. C.—Concrete pipe.

FIG. D.—Laying concrete pipe.

rounded, but approximate a trapezoidal shape; the side slopes will usually approach a slope of about 1 1/2 horizontal to 1 vertical. The selection between a broad shallow ditch and a deep narrow ditch will depend on the principles of flow, stated above, and the method of construction. A broad, shallow ditch will hold a larger part of the volume of water above the natural ground surface, and because of the smaller velocity which it will give is a more desirable form of cross section for steep grades. Mr. F. W. Hanna, formerly Project Engineer on the Payette Boise, U. S. Reclamation Service project, has given the following rule for determining the relative dimensions of bottom width (b) and depth (d) in laterals:

$$b = d^2 + 1 \text{ where the grade of the ditch is small,}$$
$$b = 2d^2 + 2 \text{ where the grade of the ditch is large.}$$

This rule conforms with good practice and may be applied to farm ditches. The carrying capacity of typical cross sections of farm ditches is given in the table below. The theoretical cross sections on which these computations are based, and the average form, which these cross sections will be given either by construction or by seasoning, are given in the accompanying diagrams, Fig. 53. A side slope of 1 1/2 to 1 has been selected, as it represents about the average used for such ditches. The results are obtained from Kutter's Chezy Formula, using a coefficient of roughness equal to 0.025.

Carrying Capacities of Farm Ditches

Form No. 1. Bottom width 1.25 ft., side slopes 1 1/2 to 1

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	3 in.	6 in.	9 in.	3 in.	6 in.	9 in.
1	0.46	0.72	0.93	0.19	0.72	1.66
2	0.65	1.02	1.33	0.26	1.02	2.37
4	0.93	1.45	1.89	0.38	1.45	3.36
5	1.04	1.62	2.10	0.42	1.62	3.74
6	1.13	1.78	2.31	0.46	1.78	4.11
8	1.32	2.05	2.67	0.54	2.05	4.75
10	1.47	2.29	2.98	0.60	2.29	5.30

Form No. 2. Bottom width 1.50 ft., side slopes 1 1/2 to 1

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	3 in.	6 in.	9 in.	3 in.	6 in.	9 in.
1	0.47	0.80	0.97	0.22	0.96	1.91
2	0.67	1.13	1.37	0.32	1.36	2.72
4	0.95	1.60	1.95	0.45	1.92	3.84
5	1.06	1.79	2.18	0.50	2.15	4.28
6	1.17	1.96	2.39	0.55	2.35	4.70
8	1.35	2.27	2.75	0.63	2.72	5.41
10	1.50	2.53	3.07	0.70	3.03	6.05

Form No. 3. Bottom width 2 ft., side slopes 1 1/2 to 1

Grade in feet per thousand	Mean velocity in feet per second for depths of:				Carrying capacity in second feet for depths of:			
	3 in.	6 in.	9 in.	12 in.	3 in.	6 in.	9 in.	12 in.
0.5	0.34	0.58	0.71	0.85	0.20	0.84	1.66	2.98
1	0.49	0.82	1.00	1.20	0.29	1.19	2.35	4.20
2	0.69	1.16	1.42	1.70	0.41	1.69	3.32	5.94
4	0.98	1.65	2.01	2.41	0.58	2.39	4.71	8.43
6	1.20	2,03	2.48	2.94	0.71	2.94	5.80	10.30
8	1.38	2.33	2.84	3.40	0.82	3.38	6.65	11.90
10	1.54	2.60	3.18	3.80	0.91	3.77	7.44	13.30

Form No. 4.—Bottom width 3 ft., side slopes 1 1/2 to 1

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	9 in.	12 in.	15 in.	9 in.	12 in.	15 in.
0.5	0.76	0.90	1.04	2.34	4.05	6.35
1	1.09	1.30	1.50	3.38	5.85	9.15
2	1.55	1.85	2.13	4.80	8.35	13.00
4	2.20	2.62	3.00	6.82	11.80	18.35
6	2.69	3.22	3.70	8.34	14.50	22.60
8	3.14	3.71	....	9.74	16.70	....

Form No. 5. Bottom width 4 ft., side slopes 1 1/2 to 1

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	12 in.	15 in.	18 in.	12 in.	15 in.	18 in.
0.25	0.66	0.76	0.85	3.85	5.82	8.28
0.50	0.98	1.12	1.25	5.46	8.17	11.75
0.75	1.19	1.35	1.53	6.52	10.10	14.35
1	1.37	1.59	1.77	7.53	11.65	16.57
2	1.94	2.23	2.49	10.67	16.52	23.40
4	2.75	3.15	3.54	15.12	23.40	33.20
6	3.36	3.88	4.31	18.50	28.55	41.60

Form No. 6. Bottom width 6 ft., side slopes 1 1/2 to 1

Grade in feet per thousand	Mean velocity in feet per second for depths of:				Carrying capacity in second feet for depths of:			
	2 ft.	18 in.	15 in.	1 ft.	2 ft.	18 in.	15 in.	1 ft.
0.25	1.08	0.90	0.81	0.71	19.4	11.1	7.98	5.29
0.50	1.55	1.30	1.17	1.01	27.9	16.1	11.50	7.57
0.75	1.91	1.60	1.44	1.24	34.4	19.8	14.20	9.30
1	2.21	1.86	1.68	1.45	39.8	23.0	16.60	10.90
2	3.13	2.63	2.38	2.06	56.4	32.5	23.40	15.50
4	....	3.74	3.36	2.92	....	46.2	33.10	21.90

The tabulated computations given above illustrate the principles of flow previously stated. The carrying capacity is usually known; it is determined by the known required head or stream of water; this capacity may be obtained by ditches with different cross sections, for each one of which there is a corresponding grade. The cross section to select for the known capacity depends on the grade of the canal and the velocity to be given to the water. The location of the canal may be fixed by the topography or the property lines; for instance, the canal may have to be placed along a boundary or fence line or down a ridge, in which case the size of ditch to use will be that which will give the required capacity for the given grade, unless the grade is so large that it gives an excessive velocity which will produce erosion of the beds and bank of the canal; if these conditions are obtained, it is necessary to take up the excess grade by producing a flatter grade by the insertion of drops or check gates placed at intervals. When the conditions permit a variation in the position of the ditch line, a velocity may be selected and the corresponding grade obtained from the table. The maximum velocity which may be used depends on the resistance against scouring or erosion offered by the material. For farm ditches the following safe maximum velocities may be used:

Safe Maximum Velocity in Farm Ditches

Character of material	Maximum velocity in ft. per sec.
Very fine sandy soil, or loose fine silt, or lava ash soil	0.50–1.00
Light sandy soil	1.00–1.25
Light sandy loam, or coarse loose sand	1.50–2.00
Ordinary loam, or gravelly soil	2.00–2.50
Firm soil or clay loam	2.50–3.00
Stiff clay loam	3.00–4.00

FLUMES FOR FARM DISTRIBUTION SYSTEMS

Flumes may be built without a superstructure, in which case the flume box is supported directly on the ground, or may be elevated above the ground usually by trestle construction.

When supported directly on the ground, the flume box is either built of wood or of concrete. This form of construction is largely limited to the furrow method of irrigation; the flumes are placed as head flumes along the upper end of furrows and as supply flumes connecting the head flumes, in the manner fully described under the furrow method of irrigation.

Elevated flumes are used to convey the water across depressions.

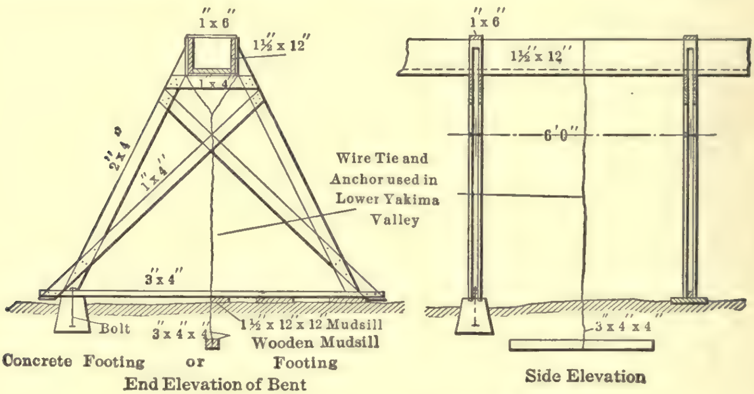


FIG. 54.—Typical small wooden flume.

The usual form of construction consists of the wooden flume box supported on trestle frames or posts. During the past few years the use of semicircular steel flumes, made of sheets of metal joined together, has been introduced by a number of manufacturers. These metal flumes, while usually more expensive than wooden flumes, are more durable and water-tight, and have been used quite extensively, especially for larger flumes. The dimensions, prices and carrying capacities of metal flumes, and the design of the trestle, are given in the descriptive catalogues prepared by the various manufacturers. The use of wooden and concrete bench flumes for the division of water in the furrow method of irrigation has been described. Flumes are also used extensively on rolling lands for the crossing of depressions; for these topographic condi-

tions either the furrow method of irrigation or the wild flooding method is used, and small streams of water usually less than 2 or 3 cubic feet per second must be carried. Larger streams of water are

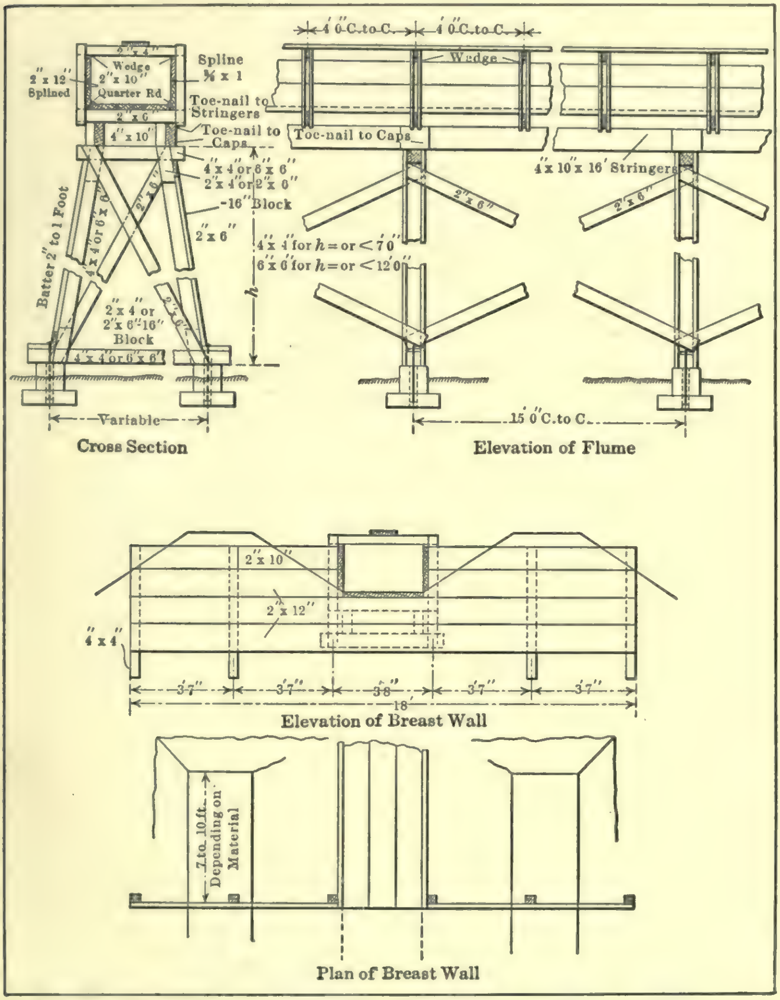


FIG. 55.—Type of timber flume. Sun River Project, Montana.

generally used only for large farms and for some of the check flooding methods practised on the flat valley lands of some sections of California and Arizona, where depressions seldom occur.

The engineering design of flumes is considered in Volume II; only the smaller flumes will be considered in this chapter.

The accompanying illustrations show two types of elevated wooden flume construction. The design of the smaller size flume, Fig. 54, Pl. VI, Fig. B, is well adapted to flumes up to about 10 to 12 inches in height and 18 to 24 inches in width; the floor is made of a single board up to 12 inches in width, when two boards are used. For the smaller sizes up to 8 by 10 inches or 10 by 12 inches, boards 1 inch thick and 1 1/2 inches thick are commonly used; 1 1/2-inch boards will make a stronger and more durable flume, not as liable to crack. The flume is supported on frames spaced from 4 to 8 feet apart, when carrying a maximum depth of water of 10 inches in the flume. For an 8-ft. span between supports, 2-inch boards should be used. The wire loop around the flume box, midway between the supporting frames, and connected to a buried timber, has been used in the Lower Yakima Valley, Washington, where the flume was exposed to strong winds, to anchor the flume against overturning by the wind. For larger flumes and where the height of the framed trestle is above 10 to 15 feet, the design for the larger size is best, Fig. 55. The flume box is supported on stringers which permit a larger spacing between supports. The added cost of the stringer is more than balanced by the saving in cost of the fewer number of framed bents. The trestle frames may be supported on mud sills or on concrete footings, to which they should be bolted to obtain greater resistance against overturning by the winds.

To connect the ends of the flume with the earth ditch, the flume ends should be carried well into the firm ground, and the connection made with a cut-off toe wall and wings, around which the material is well puddled. Where the velocity in the flume is to be much greater than in the ditch, the slopes and bed of the ditch should be protected with stone riprap or a short section of concrete lining 2 or 3 inches thick, about 10 feet in length. To pass from a lower velocity in the ditch to a higher velocity in the flume, it is necessary to place the inlet of the flume low enough to obtain a small fall from the water level in the ditch to the water level in the flume. In passing from a 2-foot velocity in the ditch to a 4-foot velocity in the flume, this fall should be about 3 inches; in passing from a 2-foot velocity to a 6-foot velocity, it should be about 8

inches. Where the change in velocity is considerable, the inlet and outlet should preferably be shaped so as to taper gradually from the trapezoidal ditch section to the rectangular flume section. For short flumes it is preferable not to make any considerable change in the velocity of the water.

Carrying Capacity of Flumes.—The carrying capacities of different sizes of rectangular wooden flumes are tabulated below. The computations are based on Kutter's Chezy Formulæ, using a coefficient of roughness equal to .012. The carrying capacities of rectangular concrete flumes, may be obtained with sufficient degree of accuracy from the same table, by subtracting from the values given a correction equal to 1/10 of these values.

Carrying Capacities of Small Rectangular Wooden Flumes

Size No. 1. Inside width = 10 in.

Grade in feet per thousand	Mean velocity in feet per second for depths of:		Carrying capacity in second feet for depths of:	
	3 in.	6 in.	3 in	6 in.
1	1.03	1.33	0.214	0.575
2	1.46	1.96	0.304	0.816
3	1.79	2.40	0.373	1.00
4	2.06	2.77	0.429	1.15
5	2.30	3.10	0.479	1.29
6	2.53	3.40	0.527	1.42
8	2.92	3.92	0.608	1.63
10	3.26	4.38	0.679	1.82
20	4.61	6.20	0.961	2.58

Size No. 2. Inside width = 12 in.

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	3 in.	6 in.	9 in.	3 in.	6 in.	9 in.
1	1.10	1.50	1.73	0.27	0.75	1.30
2	1.55	2.12	2.45	0.39	1.06	1.84
3	1.90	2.61	3.01	0.45	1.30	2.25
4	2.19	3.00	3.46	0.55	1.50	2.60
5	2.40	3.36	3.88	0.60	1.88	2.91
6	2.69	3.68	4.25	0.67	1.84	3.19
8	3.10	4.25	4.90	0.77	2.12	3.68
10	3.47	4.75	5.48	0.87	2.37	4.12
20	4.99	6.70	7.72	1.25	3.35	5.19

Size No. 3. Inside width = 18 in.

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	6 in.	9 in.	12 in.	6 in.	9 in.	12 in.
0.5	1.18	1.40	1.54	0.88	1.58	2.31
1	1.70	2.00	2.20	1.27	2.25	3.30
1.5	2.08	2.45	2.71	1.56	2.76	4.07
2	2.43	2.83	3.13	1.82	3.18	4.69
3	2.97	3.49	3.87	2.23	3.93	5.80
4	3.43	4.03	4.47	2.57	4.54	6.70
5	3.84	4.50	5.00	2.88	5.07	7.50

Size No. 4. Inside width = 24 in.

Grade in feet per thousand	Mean velocity in feet per second for depths of:			Carrying capacity in second feet for depths of:		
	6 in.	9 in.	12 in.	6 in.	9 in.	12 in.
0.5	1.28	1.53	1.73	1.28	2.29	3.46
1	1.85	2.20	2.49	1.85	3.31	5.10
1.5	2.27	2.70	3.06	2.27	4.03	6.12
2	2.62	3.11	3.53	2.62	4.67	7.06
3	3.21	3.82	4.33	3.21	5.73	8.66
4	3.70	4.40	5.00	3.70	6.60	10.00
5	4.13	4.94	5.59	4.13	7.38	11.18

PIPES FOR FARM DISTRIBUTION SYSTEM

Pipes are used in the conveyance and distribution of water on the farm for the following purposes:

First. In the place of earth ditches to convey the water to the different parts of the farm. This practice has been confined largely to the use of cement pipe systems of irrigation in southern California; and to wood pipe or steel pipe systems in British Columbia, Idaho, Washington, and southern California.

Second. For the application of water on the land by the surface pipe method of irrigation. This is usually done with the slip joint detachable metal pipe, which has been previously described.

Cement or Concrete Pipe.—The pipe so extensively used in Southern California is made in sections 2 feet long, Plate VI, Fig C One end of the pipe tapers in and the other end tapers out so that the pipes when joined together form a bevelled lap joint. This form of joint is preferred to the bell joint obtained with sewer pipes, because the outside of the pipe is straight, which

makes the pipe easier to lay; it also requires less material to manufacture. The pipe is made by tamping carefully in collapsible metal moulds, a comparatively dry mixture of one part of cement to three or four of sand and gravel. The mixture must not be too moist, for the moulds are removed immediately after the tamping is finished. After the removal of the forms, the pipe must be carefully cured by being kept moist for at least one week, and after a period of about 1 month it is ready to be laid in the trench and the sections joined together with mortar, Plate VI, Fig. D. To obtain good pipe requires careful and experienced workmanship, and except for large farms it is usually preferable to obtain the pipe from a reliable pipe contractor. The details of manufacture will, therefore, not be considered in this chapter, and the cost data and properties of the pipe given below are for pipes made of 1 to 3 and 1 to 4 mixtures, for sizes up to 18 inches diameter, which is about the largest size ordinarily used on the farm.

Cost of Making, Laying, Trenching, and Hauling Cement Pipe in Cents per Lineal Foot

Diameter of pipe in inches	Cost of making		Cost of laying	Cost of trenching	Cost of hauling 2 miles	Total cost	
	1 : 3 pipe	1 : 4 pipe				1 : 3 pipe	1 : 4 pipe
6	10	7	2.25	2.6	0.9	15.75	12.75
8	12	9	2.50	3.2	1.4	19.10	16.10
10	15	11	3.00	4.0	1.9	23.90	19.90
12	20	15	3.50	4.6	2.5	30.60	25.60
14	25	20	4.00	5.4	3.1	37.50	32.50
16	30	25	5.00	6.4	3.8	45.20	40.20
18	35	30	6.25	7.0	4.5	52.75	47.75

This cost data is based on trench excavation in average earth, on experienced labor, and for the following prices of labor and material: Cement $3.50 a barrel; gravel $1.00 a cubic yard; labor tampers $3.00 a day; mixers and sprinklers $2.50 a day. The contractor's prices will usually be from 10 to 20 per cent. higher.

The pipe as manufactured is not very dense and will not stand high pressures. The following values may be used for the maximum safe pressure head, if the pipe is properly made and laid:

Diameter of pipe	Maximum pressure in feet or 1 : 3 mixture	for 1 : 4 mixture
12	15	10
14	15	10
16	12	8
18	12	8

In heavy soils, which do not have good drainage, leaks through the pipe and through contraction cracks, will soften the surrounding soil and may produce settlement of the pipe, resulting in breaks. For these conditions, wooden or steel pipes are preferable, specially for pressures approximating the maximum given above.

Vitrified Clay Pipe.—Vitrified clay pipe in some localities may be cheaper for the small sizes. The pipe itself is less permeable than concrete pipe, but as the strength of a pipe line against permeability is largely dependent on the strength of the joints and as contraction cracks will occur at the joints, it cannot be used for pressure heads much greater than cement pipe.

Wooden Pipes.—The wooden pipes ordinarily used on the farm are made in sections at the factory and joined together in the trench. The pipe is formed of wooden staves with radial edges bound tightly together by one or two wires wound continuously in a spiral. The pipe is manufactured in sizes from 2 to 24 inches. One end of the section is made bevelled, and the other end is surrounded with a wire-wound wooden collar which forms a bell. Connections and gate valves are made of cast iron fittings, such as air valves, or small wrought-iron pipe takeouts can be screwed directly in the staves.

The prices of wire-wound wood pipe, safe for 75 to 100 feet pressure head are about as follows for the Pacific Coast States, where large quantities are used and the prices low:

Diameter of pipe in inches.	6	8	10	12	14	16	18	20	22	24
Cost per lineal foot.......	.17	.22	.30	.35	.50	.60	.68	.75	.90	1.00

Steel Pipes.—The pipe commonly used is made of lengths of steel sheets rolled and riveted longitudinally, or may be made of sheets riveted spirally. Each section of pipe is usually 20 to 25 feet in length, and is connected by slip joints for low pressures, or by bolted or flanged joints. The pipe is usually protected by galvanizing or by an asphalt coat. Special fittings, such as

irrigation hydrants and slide valves, are used for low pressures, which cost very much less than the standard fittings used for high pressures.

The prices of riveted steel slip joint pipes, safe for pressure heads of 200 feet, is about as follows for the Pacific Coast:

Diameter of pipe in inches..........	4	6	8	10	12	14	16	18	20	22	24
Gauge of metal.....	16	16	16	14	14	12	12	12	10	10	10
Price per lineal ft...	$.18	.26	.32	.45	.55	.75	.85	96	1.30	1.45	1.55

Carrying Capacities of Pipes.—The carrying capacities of different sizes of concrete pipes are tabulated below. The computations have been made by Kutter's Chezy Formula, using a coefficient of roughness equal to 0.0135, which is very nearly the average value obtained by measurements made on a number of concrete pipe lines of this character on the Umatilla project in Oregon.

CARRYING CAPACITIES IN CUBIC FEET PER SECOND OF CONCRETE PIPES LAID IN SECTIONS 2 FT. LONG. NO CORRECTION MADE FOR ENTRANCE AND OUTLET LOSSES

Head in feet per 1000 ft. for friction.	Carrying capacity of pipe when running full without correction for entrance or outlet losses									
	6 in.	8 in.	10 in.	12 in.	14 in.	16 in.	18 in.	20 in.	22 in.	24 in.
0.5	0.104	0.230	0.428	0.712	1.105	1.58	2.18	2.92	3.78	4.80
0.6	0.114	0.251	0.468	0.780	1.208	1.72	2.39	3.20	4.14	5.25
0.7	0.123	0.272	0.507	0.843	1.308	1.86	2.58	3.46	......	......
0.8	0.132	0.290	0.541	0.900	1.395	1.99	2.76	3.69	4.47	6.07
0.9	0.140	0.308	0.573	0.954	1.48	2.11	2.93	3.91	5.07	6.44
1.0	0.147	0.324	0.604	1.006	1.56	2.22	3.08	4.12	5.33	6.78
1.5	0.180	0.397	0.740	1.231	1.91	2.72	3.77	4.92	6.54	8.30
2.0	0.208	0.458	0.855	1.423	2.20	3.14	4.35	5.83	7.55	9.58
3.0	0.255	0.562	1.05	1.745	2.70	3.86	5.34	7.15	9.25	11.75
4.0	0.294	0.648	1.21	2.01	3.12	4.45	6.16	8.25	10.67	13.55
5.0	0.329	0.726	1.35	2.25	3.49	4.97	6.89	9.22	11.93	15.16
6.0	0.361	0.796	1.48	2.47	3.82	5.45	7.55	10.11	13.09	16.62
7.0	0.390	0.859	1.60	2.66	4.13	5.89	8.16	10.91	14.12	17.95
8.0	0.416	0.918	1.71	2.84	4.41	6.29	8.71	11.66	15.09	19.17
9.0	0.442	0.974	1.81	3.02	4.68	6.67	9.25	12.38	16.0	20.35
10.0	0.466	1.026	1.91	3.18	4.93	7.04	9.75	13.05	16.89	21.44
12.0	0.510	1.125	2.09	3.48	5.40	7.70	10.68	14.3	18.5	23.5
14.0	0.551	1.216	2.26	3.76	5.83	8.33	11.53	15.43	19.97	25.4
16.0	0.588	1.300	2.42	4.02	6.23	8.90	12.34	16.50	21.37	27.16
18.0	0.625	1.378	2.57	4.27	6.61	9.44	13.10	17.52	22.68	28.8
20.0	0.656	1.448	2.69	4.48	6.95	9.92	13.75	18.4	23.8	30.26
25.0	0.736	1.623	3.02	5.03	7.79	11.13	15.44	20.65	26.7	33.97
30.0	0.806	1.778	3.31	5.51	8.53	12.2	16.90	22.60	29.28	37.2

The carrying capacities of pipe lines made of vitrified clay pipe will be about the same as those given in the table for concrete pipe. Wooden pipes have a carrying capacity about 15 per cent. larger than the values given. Riveted steel pipe will have a carrying capacity about 10 per cent. smaller than the values given.

In this table the loss of head at the inlet and outlet, due to the irregular currents resulting from the change in cross section in passing from the ditch to the pipe, has not been considered. This loss of head is dependent on the change in velocity and the form of inlet and outlet structure; the allowance to be made is considered in the discussion of siphons and culverts.

SIPHONS

The type of structure used in irrigation, commonly named as a siphon, is not a true siphon but an inverted siphon. Inverted siphons are used where the land is rolling and it is necessary to carry the water from one ridge or one knoll to another; or to carry the water under a stream or to cross under a lower ditch, roadway, etc. The depression is crossed by the pipe or conduit which connects at the upper and lower end to inlet and outlet structures. The flow through the siphon depends mainly on the difference in elevation between the inlet and outlet, the size of the conduit, and the form given to the inlet and outlet. Where the conduit is very short it is practically a culvert, and the table of flow given for culverts may be used. For longer conduits it is necessary to consider the additional frictional resistance due to the greater length of pipe.

The required difference in elevation between the water surfaces of the inlet and outlet to produce a certain discharge through a siphon with a conduit of a fixed diameter, may be obtained with sufficient accuracy by adding to the difference in levels for a short culvert as given in the table, the fall between inlet and outlet required to overcome the frictional resistance in the added length of pipe; this is obtained from the table of flow given for pipes.

The connections with the ditch at the inlet and outlet are usually built alike, Fig. 56. Where the connection is in firm soil which will puddle well, the simplest form of construction is obtained by extending the end of the conduit in a breast wall at right angles to the line of the canal; the wall is carried on each

side well into the banks of the ditch and below the grade of the ditch at least 18 inches to 2 feet. To form a tapered or funnel-

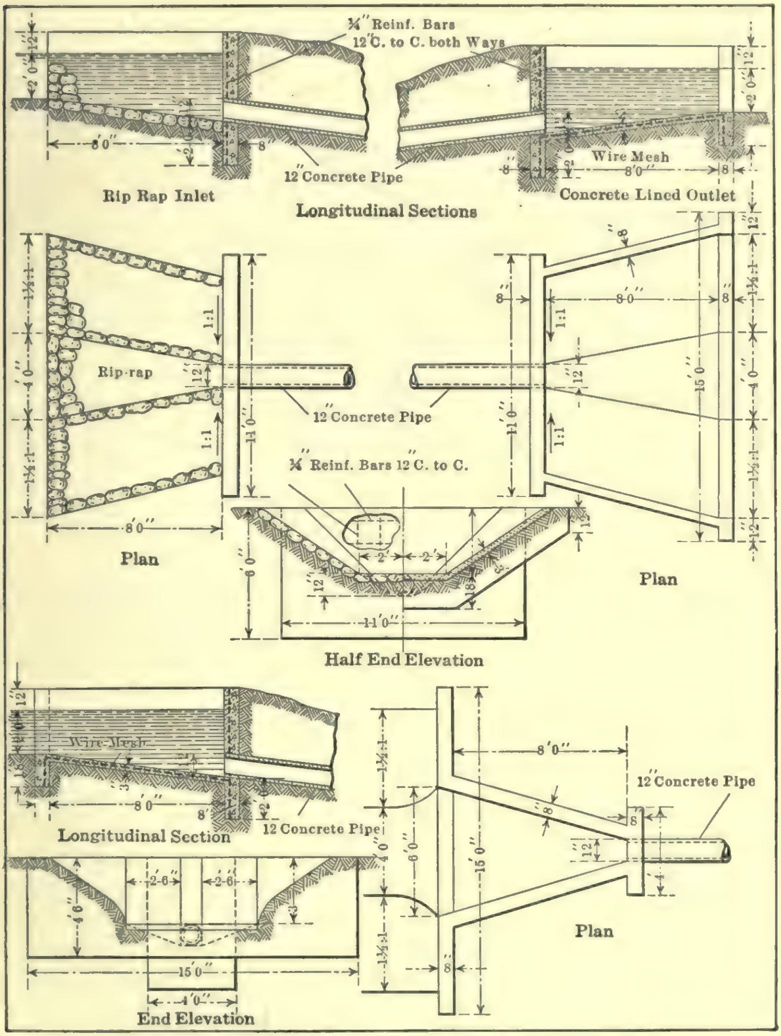


FIG. 56.—Inlets and Outlets for siphons.

shaped inlet or outlet and to protect the adjacent section of the ditch from erosion, the sides and bed may be shaped with stone riprap or with a concrete lining about 3 inches thick ending with

a cut-off wall extending into the earth about 12 inches. Where the ends of the siphon are in loose soil or on comparatively steep slopes and where there is danger of washing under or around the connecting structures, a more substantial structure may be formed by adding to the abutment wall, wings and a floor with a cut-off wall carried into the earth.

The conduit of the siphon is generally a concrete, vitrified clay, steel or wood pipe. The plain concrete pipe, of the type previously described, must not be used where the pressure head is greater than the values which have been given. Vitrified clay pipe cannot be used for pressures much greater than cement pipe. Reinforced concrete pipes have been used successfully for pressure heads corresponding to over 100 feet, but their use is largely limited to heads under 50 feet. Wood banded or wood stave pipes and steel pipes are used for higher pressures. The design of larger siphons and more complete consideration of reinforced concrete and wooden pipes are taken up in a separate chapter of Volume II.

STRUCTURES USED ON FARM DITCHES

The type and size of structures will depend on the size of the ditches and the method of irrigation. To regulate and control the water in the ditches the following structures may be required: (1) Drops to absorb the excess in grade, when the grade of the surface, on the line of the ditch, is larger than the grade which may be given to the ditch without producing an excessive velocity. (2) Check gates to regulate and raise the water level in the ditch in order to permit diversion from the ditch into one or more field ditches, or to deliver the water on the land through cuts in the banks or through levee gates. A drop is generally used also as a check gate. (3) Headgates for field ditches. (4) Division boxes to divide the water between two ditches. (5) Levee gates to control the water delivered from a ditch through an opening made in the bank of the canal or in the levee of a check. (6) Culverts and bridges for road crossings. (7) Stock guards.

Some of the smaller devices for distributing the water from the field ditches have been previously described in the discussion of the methods of irrigation. A few examples of typical structures used on farm ditches are presented by the following illustrations.

These structures are designed and used for farm ditches of comparatively large capacities, more specially adapted to the methods of irrigation where large heads of water are used, such as in the check method and border method of flood irrigation.

DROPS AND CHECK GATES

A simple type of concrete drop is that used on the lateral system of the Orland project, California, Fig. 57. It consists of a breast wall across the canal with a rectangular opening regulated with flashboards, which permits using the structure

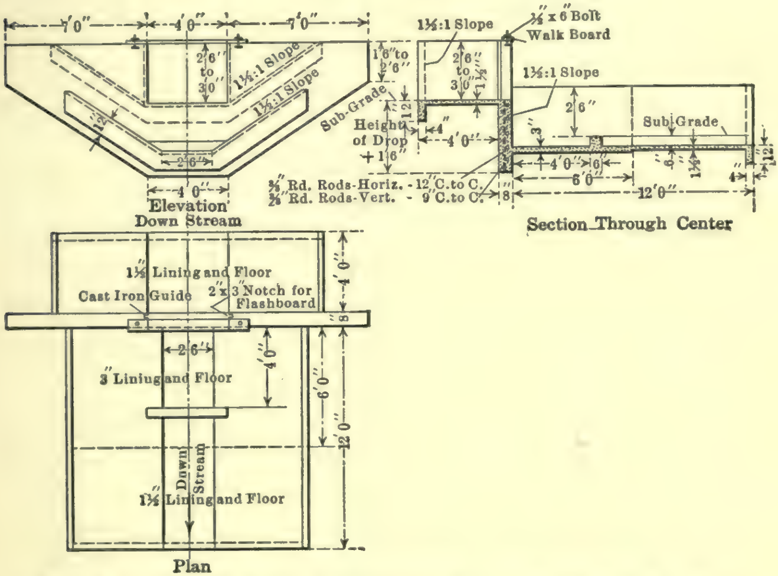


FIG. 57.—Standard design of check and drop. Orland Project, Cal.

for a check gate; a concrete lining on the sides and floor of the downstream side with a shallow water cushion to resist the impact of the falling water, and a concrete lining 1 1/2 inches thick on the upstream side. The total cost of labor and material, including excavation and backfilling, for 376 such structures averaged $36.58 for the larger sized structure with a 1-foot drop, containing 3.2 cubic yards of concrete, and $30.88 for the smaller size, containing 2.7 cubic yards of concrete.

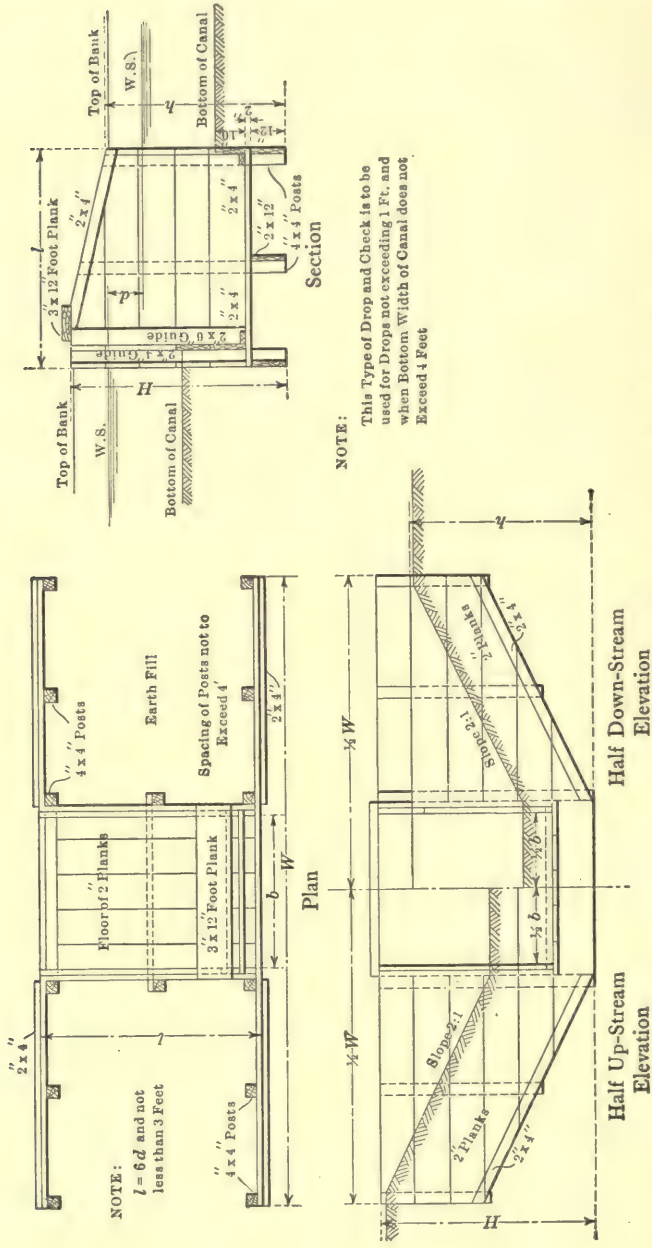


FIG. 58.—Wooden drop and checkgate for laterals. Milk River Project, Montana.

A standard type of wooden drop and check gate for ditches having a bottom width of 4 feet or less and for a height of drop of

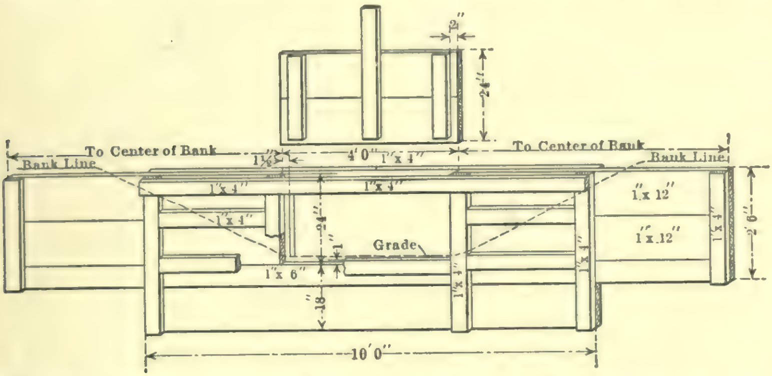


FIG. 59.—Single wall checkgate. Sacramento Valley Irrigation Co., Cal.

1 foot or less is illustrated by the design used on the smaller laterals of the Milk River project in Montana, Fig. 58. In the San Joaquin and Sacramento Valley in California, in drop struc-

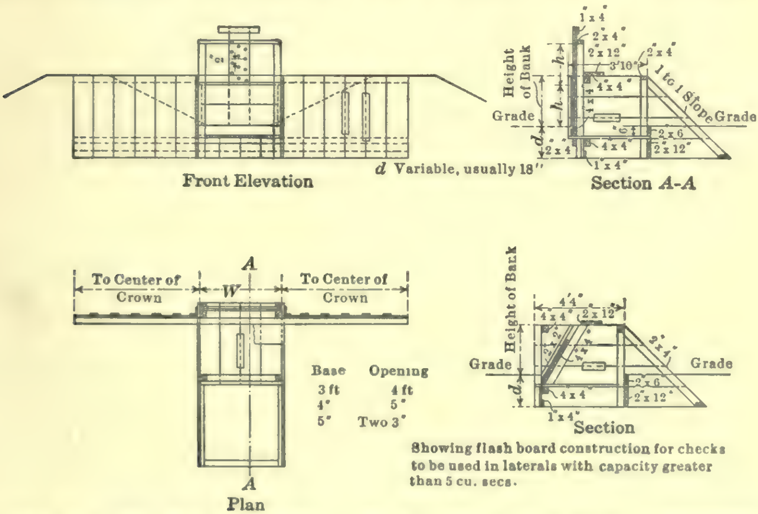
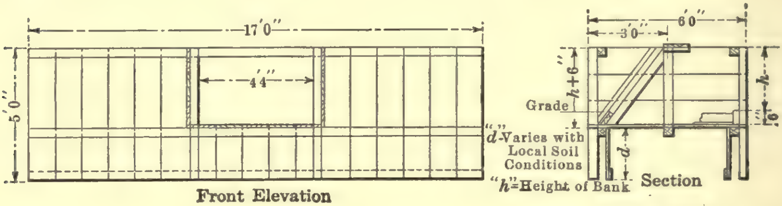


FIG. 60.—Single wall checkgate with sidewalls and floor. Sacramento Valley Irrigation Co., Cal.

tures used as check gates, the flashboards to regulate the opening between the side walls are commonly placed in grooves

inclined downstream, as shown by one of the check-gate designs of the Sacramento Valley Irrigation Company. The advantages of sloping flashboards are that the water pressure on them gives greater stability to the structure, the flashboards have less tendency to float up when the water level on the downstream side backs up, and it is easier to stop the leaks between flashboards with earth or manure thrown against the upstream face.

Drop structures used on a farm distribution system are generally low drops and used also as check gates.



Lumber

Size	Length	No. Pcs.	B.M.
1 x 12	20	7	140
	18	4	72
1 x 4	20	6	40
	18	3	18
	16	1	5
	14	2	9
4 x 4	20	2	53
	18	4	96
2 x 12	6	1	12
2 x 6	10	1	10
2 x 4	12	1	8
			463
	d =	2′0″	
	h =	2′6″	
	Flash Boards		
2 x 6	4′9″	5	24

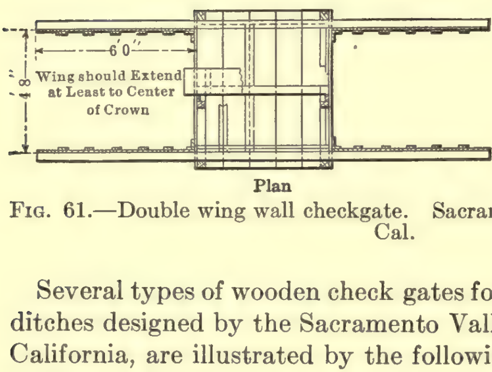


FIG. 61.—Double wing wall checkgate. Sacramento Valley Irrigation Co., Cal.

Several types of wooden check gates for small laterals and farm ditches designed by the Sacramento Valley Irrigation Company, California, are illustrated by the following drawings:

The simplest form is a single wall check gate with an opening controlled by a straight lift gate, Fig. 59. The width of the opening is about the same as the bottom width of the canal; it is 3 feet 8 inches wide and 2 feet deep; and is used for canals having a capacity of about 4 to 6 cubic feet per second. This type of structure is satisfactory for heavy soil, which when well puddled around the wings and cut-off toe wall will prevent undermining

or washing around the structure. In soil which is more porous and more easily eroded by the water passing through the gate opening the channel below the gate opening is formed by two side walls and a floor, and either a straight lift undershot gate or flashboards placed on a slope are used to control the opening, Fig. 60. In lighter porous soil a double wing check gate is used

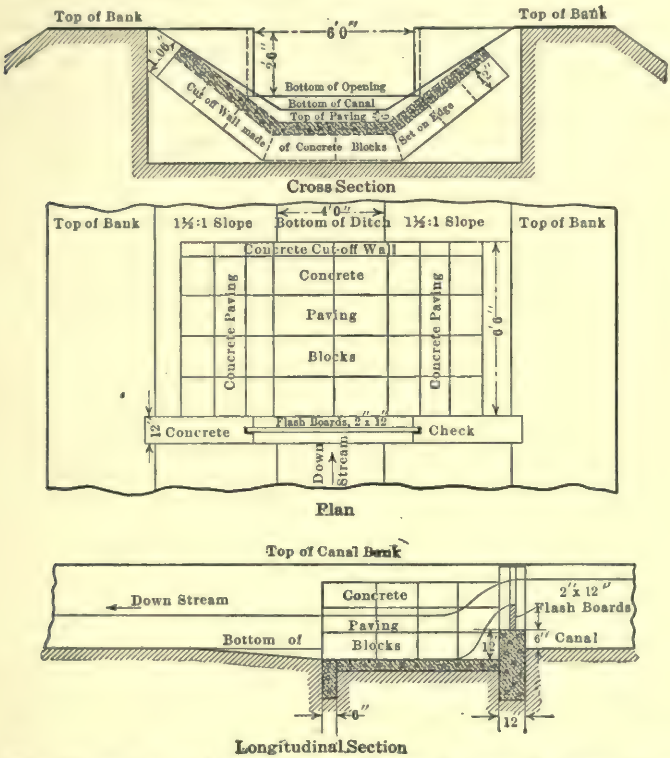


FIG. 62.—Concrete check for small laterals. Huntley Project, Montana.

to offer greater resistance against washing around and under the structure, Fig. 61.

A simple type of concrete check gate, very similar to the combined drop and check gate used on the Orland project and described above, is shown by the type of check-gate used on the Huntley project, Montana, on ditches carrying 5 to 20 cubic feet per second, Fig. 62. The ditch sides and bed on the downstream side of the breast wall are protected with concrete paving blocks.

A concrete lining 3 inches thick, reinforced with wire mesh, could be used as a desirable substitute.

Head Gates, Division Gates, Levee Gates.—Head gates and division gates for field ditches may be made practically the same as check gates. Division gates may control and divide the flow between two ditches or may divide the flow between one ditch and two other ditches, one on each side and at right angles to it, the division box consisting of a head gate to each ditch. The type of concrete structures used on the University Farm at Davis, California, for the distribution system for alfalfa irrigation by the border method represents good practice in the Sacramento

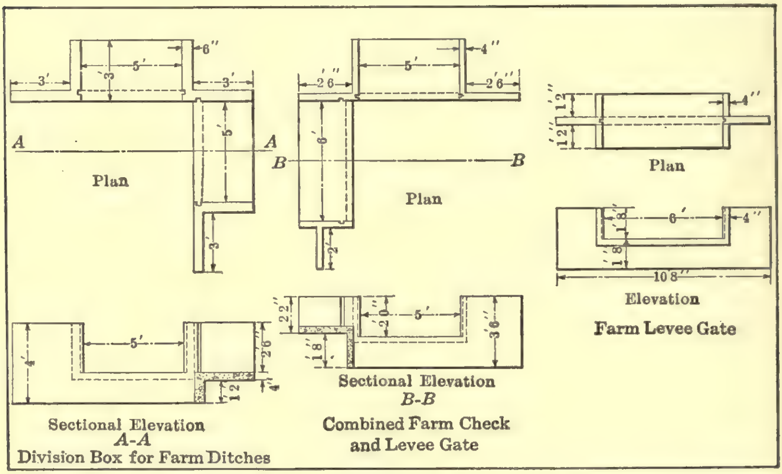


FIG. 63.—Structures on farm distribution system for alfalfa irrigation by border method. University Farm, Davis, Cal.

and San Joaquin Valley, Fig. 63. These structures are built in an average sandy loam and are designed for a maximum capacity in the field ditches of 12 to 16 second feet and for delivery in the checks or borders through the levee gates of 4 to 6 second feet. The division box is designed for division of water between two field ditches. The combined farm check gate and levee gate is located where a check gate is required and can be combined with a levee gate to save in cost of construction. The floor of the levee gate is made about flush with the ground surface and is 6 inches higher than the floor of the check gate, which is level with the canal grade. This check gate will usually raise and control the

water level for several levee gates on the upstream side. The levee gate is set in place with the cut-off wall and toe wall in the center of the bank of the canal. The grooves for the gates should be tapered so as to be larger on the outside than on the inside and preferably lined with thin galvanized iron. The tapered grooves will be easier formed, without breaking off at the edges, and are less liable to cause the gates to stick when the wood swells. It is desirable to strengthen the junction of the walls by placing a few strands of wire or light reinforcement around the corners.

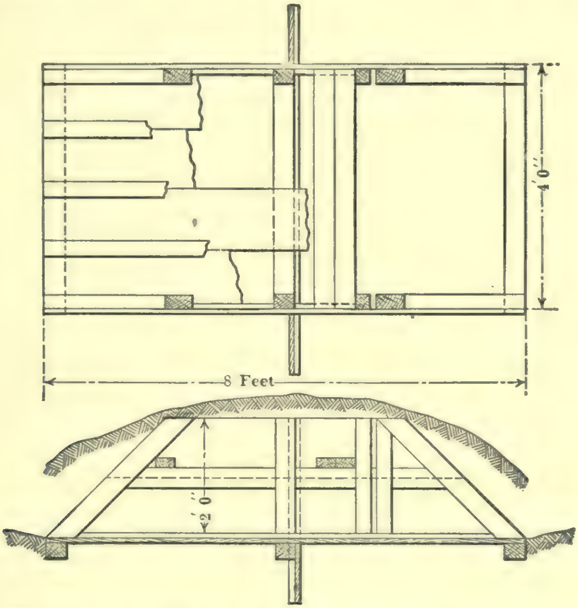


Fig. 64.—Wooden levee gate for check flooding irrigation used near Manteca, Cal. From O. E. S. Bull. 145, U. S. Dept. of Agriculture.

A small drop of about 6 inches may be provided for at each check gate by maintaining the sill of the gate opening at the level of the ditch bed on the upstream side and building the floor level with the ditch bed on the downstream side. The form of levee gate for check or border flooding will depend also on the character of the material. For heavier soils the levee gate may be a single wall gate as illustrated by the check gate of the Sacramento Valley Irrigation Company described above. For an average sandy loam soil the box type with cut-off wings and cut-off

toe wall on the center line of the levee should be used; this type is illustrated by the concrete levee gate on the University Farm at Davis, California, and by the similar wooden gate used near Manteca, Cal., Fig. 64. For the lighter soils a double wing type of levee gate may be necessary, this is illustrated by the type used on some farms in the Imperial Valley, Fig. 65.

The stability of these structures will depend largely on the care taken in backfilling; the material should be either very carefully tamped around the structure or should be well puddled with plenty of water.

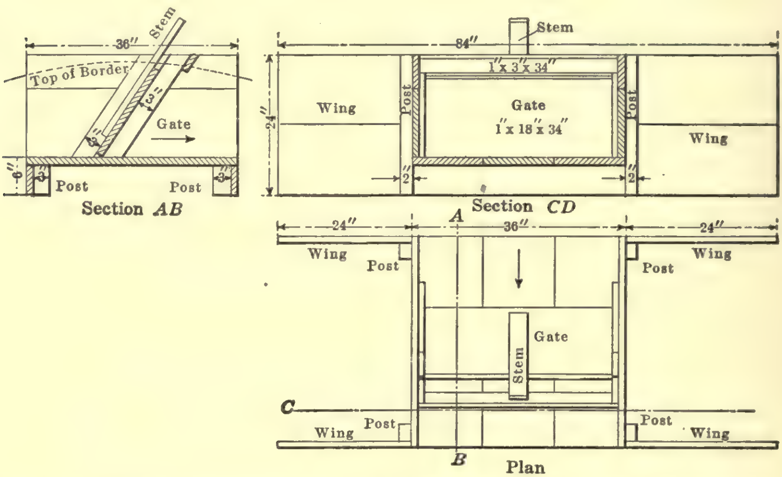


FIG. 65.—Double wing levee gate for border irrigation, Imperial Valley, Cal. From Farmers' Bull 373, U. S. Dept. of Agriculture.

Road Crossings: Culverts and Bridges.—Road crossings over permanent field ditches are often necessary; they may be either culverts to carry the water under the roadway or bridges. For small ditches culverts will usually be the best and cheapest form of construction. Culverts consist of a conduit with suitable inlet and outlet connections. The conduit is usually made of pipe which may be vitrified sewer pipe, corrugated metal pipe or cement concrete pipe. The pipe will usually be subject to heavy loads, such as traction engines; it is therefore necessary that it be selected and constructed for these conditions. Plain cement concrete pipe without reinforcement and as commonly made by using a comparatively dry mixture of cement and sand or gravel is not

as suitable as sewer pipe or corrugated metal pipe. A minimum earth covering of 12 to 18 inches is necessary to protect the pipe from shocks and to distribute the load on the pipe. This form of road crossing is illustrated by the design used on the Milk River

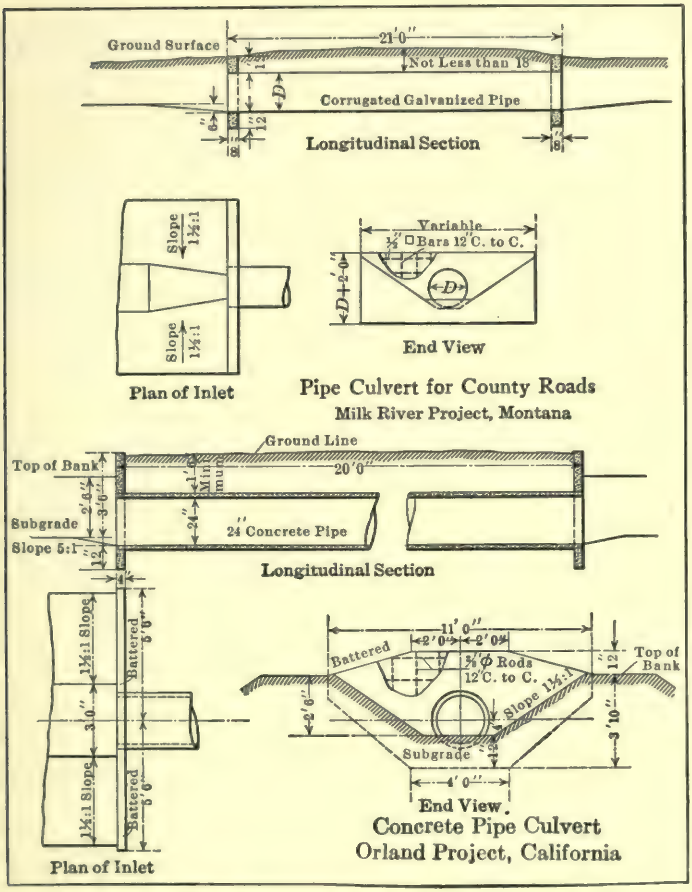


FIG. 66.—Type of pipe culverts.

project in Montana and on the Orland project in California, Fig. 66. On the Orland project the pipe is a 24-inch concrete pipe; it is used for capacities up to about 15 cubic feet per second; for larger capacities a stringer bridge is used. The size of pipe to use will depend on the capacity of the ditch and the amount of fall be-

tween the water levels of the inlet side and outlet side, which may be spared. The necessary differences in elevation between inlet and outlet water levels for different sizes of pipes and different capacities are given in the table.

Capacities of Pipe Crossings About 20 Feet in Length for Corresponding Differences in Elevation between Inlet and Outlet Water Levels

Difference in levels in inches	2	4	6	8	10	12	14	16	18
Capacity in sec. ft. for									
6-in. pipe..	0.45	0.60	0.75	0.85	0.95	1.05	1.15	1.20	1.30
12-in. pipe..	1.85	2.62	3.20	3.70	4.15	4.55	4.90	5.24	5.55
18-in. pipe..	4.25	6.00	7.30	8.45	9.45	10.35	11.15	11.95	12.65
24-in. pipe..	7.90	11.20	13.70	15.85	17.70	19.40	20.95	22.40	23.75
30-in. pipe..	12.90	17.70	21.70	25.00	28.00	30.70	33.15	35.40	37.60

These capacities are obtained for pipe crossings of the type shown in the illustrations, in which the pipe is about 20 feet long and makes right-angle connections with the end walls. The capacities may be increased a small amount by forming flaring or funnel-shaped inlets and outlets, which, however, may increase the cost of construction by a greater amount than the use of a larger size pipe. When the difference in water levels exceeds more than 4 to 6 inches, the velocity of entrance and exit will be greater than ordinary soil can stand without erosion and it will be necessary to protect the ditch bed and slopes upstream and downstream for a distance from 6 to 10 feet with a concrete lining 3 inches thick terminating in a toe wall extending 12 inches in the earth or with a paving or riprap of rock.

Stringer bridges for field ditches usually consist of 2 by 12 or 3 by 12 flooring nailed to stringers extending across the ditch and supported at each end either on a concrete abutment wall or on a wooden cap which rests on concrete footings or wooden posts bearing on a wooden sill. The size and spacing of the stringers depends on the load and on the width of the bridge. The width of the bridge is usually about 16 feet and from 6 to 9 stringers are used. Stringers of the following dimensions are commonly used and are safe for a 20-ton traction engine:

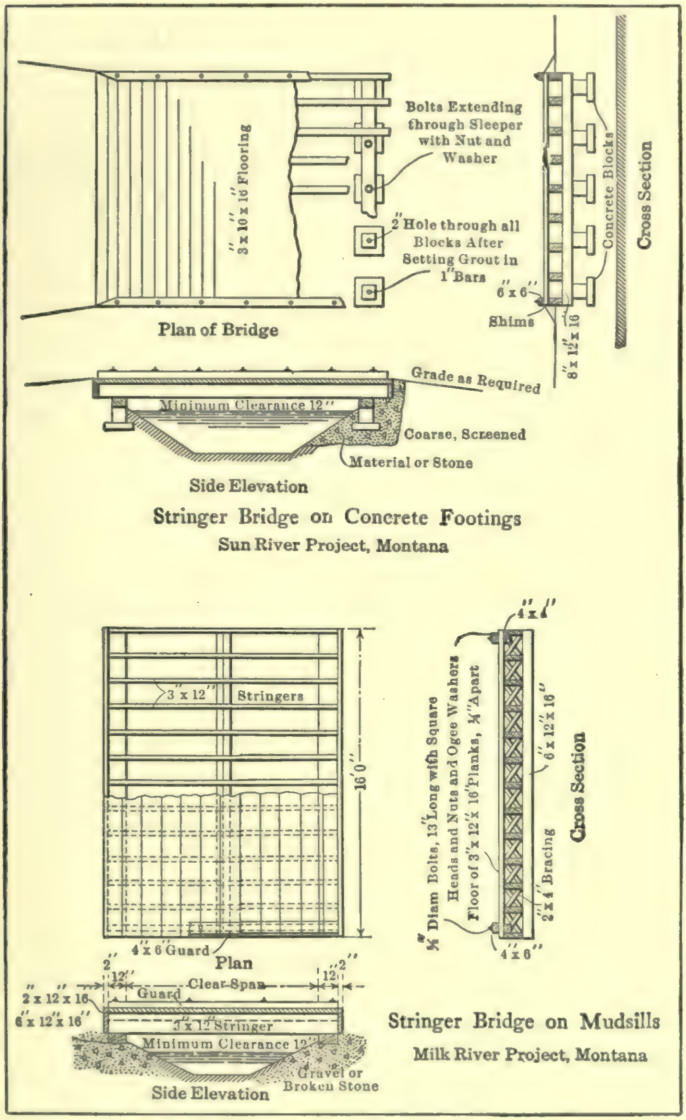


Fig. 67.—Types of stringer bridge.

Clear span in feet	Stringers No.	Stringers Size	Stringers No.	Stringers Size
6	6	3″ × 10″	9	3″ × 8″
8	6	3″ × 12″	9	3″ × 10″
10	6	3″ × 14″	9	3″ × 12″
12	6	3″ × 14″	9	3″ × 12″
16	6	5″ × 14″	9	5″ × 12″

The bridge must be built at a height that will give a depth of clearance between the full supply water level and the lower edge

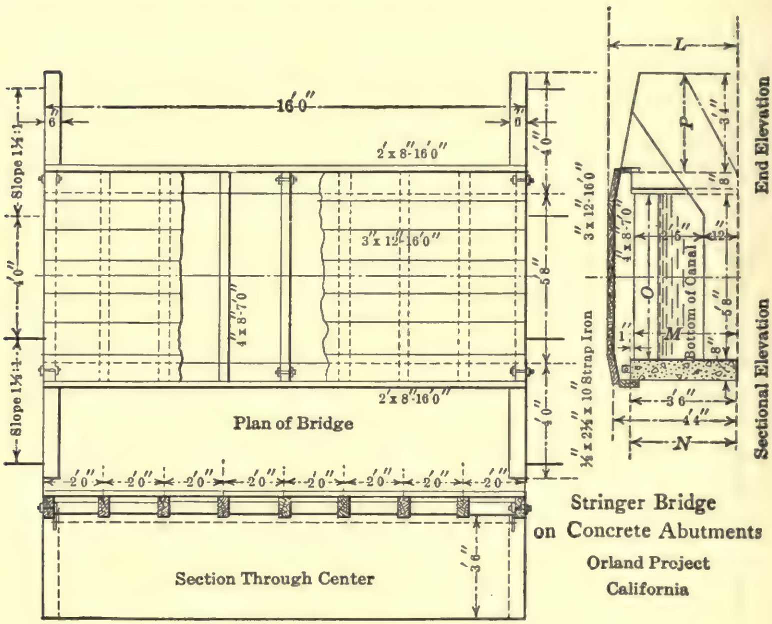


FIG. 68.—Type of stringer bridge.

of the stringer of about 12 inches. The details of stringer bridges are illustrated by the designs given for the bridges used on the Sun River project and Milk River project, both in Montana, Fig. 67, and the type used on the Orland project in California, Fig. 68. These designs differ in the character and position of the abutments. The abutments of the bridge for the Milk River project consist of a 6 × 12 mud sill placed directly on a gravel fill, which is necessary to give a firm foundation. The abutments of the bridge for the Sun River project consist of a sill placed on concrete

footings; on both of these projects the abutments are placed near the top of the bank so as not to change or contract the cross section of the ditch; on the Orland project the abutments of the bridge are concrete side walls, placed at a distance apart equal to about the average width of the ditch and connected to the earth slopes with inlet and outlet wings. The first type gives a longer span, which will require heavier stringers, but it will usually be more economical than the second type.

The complete cost, exclusive of overhead expenses, of a number of bridges built on the Orland project, is as follows:

DIMENSIONS AND COST OF STRINGER BRIDGES ON ORLAND PROJECT, CAL.

Dimensions of ditches		Dimensions of bridge						Actual Cost
Bottom width	Depth	L	M	N	O	P	Stringers	
ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	in. in. ft. in.	
8 0	4 0	5 3	4 0	4 2	10 8	4 6	4 × 12–12 0	$80.75
8 0	3 6	4 10	3 11	4 0	10 8	4 0	4 × 12–12 0	....
6 0	3 6	4 10	3 11	4 0	8 8	4 0	4 × 12–10 0	75.00
4 0	3 6	4 10	3 11	4 0	5 8	4 0	4 × 8– 7 0	67.00
4 0	3 0	4 4	3 5	3 6	5 8	3 4	4 × 8– 7 0	61.60

On the Milk River a uniform size of stringer was used for all spans and the spacing was varied according to the span. The bridges were 16 feet wide, and the stringers are 3 × 12. The number and spacing of stringers were as follows:

Clear span in ft.	No. of stringers	Spacing of stringers in inches
7	10	21
8	11	18 7/8
9	12	17 3/16
10	13	15 3/4
11	14	14 9/16
12	15	13 1/2
13	16	12 5/8
14	17	11 13/16

The amount of material in these stringers is greater than for the other two bridges; the greater strength which is obtained does not justify this heavier design except perhaps when the bridge is on a much travelled highway.

STOCK GUARDS

These are needed at fence lines to close the opening made by the ditch under the fence in order to prevent the hogs or other farm animals from escaping from the enclosure. The guard consists of a wooden frame or screen, built of the same cross section as the ditch, and hung by the top horizontal piece to pivoting points at the base of the fence posts, on each side of the

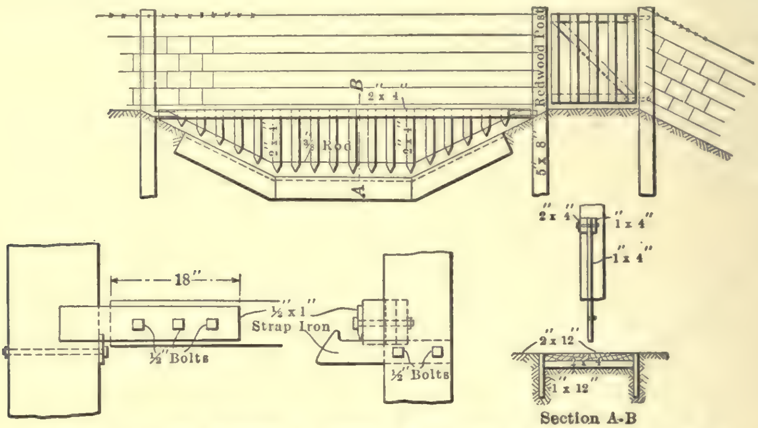


FIG. 69.—Stock guards. Sacramento Valley Irrigation Co., Cal.

ditch, Fig. 69. The guard when thus hung will swing downstream so as to offer little obstruction to the flow and will permit brush or floating material to pass without obstructing the ditch. To maintain the form of the ditch cross section, directly under the guard, the bed and sides of the ditch are protected with a lining of wood or concrete with short cut-off walls along the upstream and downstream edges.

FIG. A.—Pumping plant installation for water supply obtained from an irrigation canal.

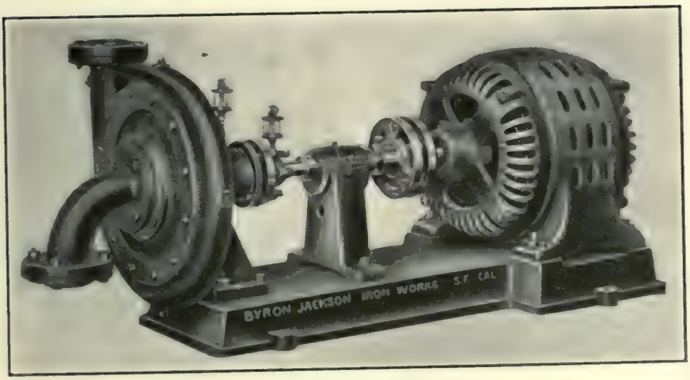


FIG. B.—Horizontal centrifugal pump, direct connected to an electric motor.

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PLATE VII

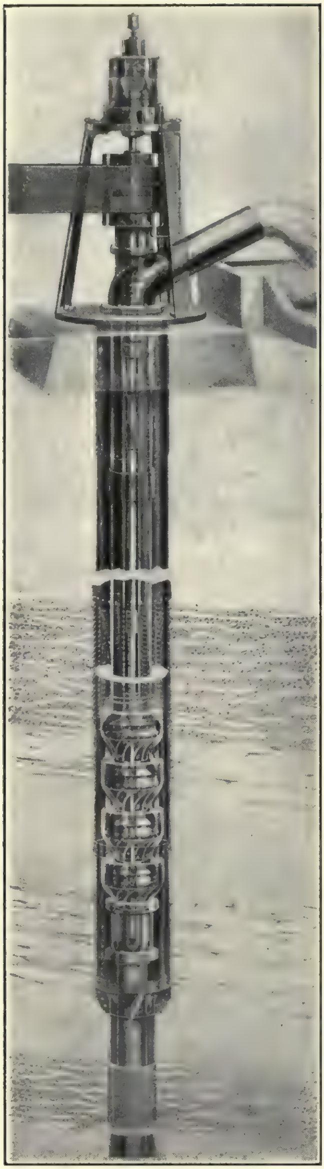


FIG. C.—Deep well turbine centrifugal pump.

FIG. D.—Air lift pump.

CHAPTER VIII

THE SELECTION AND COST OF A SMALL PUMPING PLANT

The design of pumping plants and the economic proportioning of large installations is beyond the scope of this book. This chapter deals with small pumping plants such as are commonly installed for the development of water supplies to irrigate small areas of land, generally of 160 acres or less. It is limited to a consideration of the different types of pumping plant installations, the conditions for which each type is best adapted, the cost of installation and the annual cost of operation and maintenance.

The proper selection of a pumping plant depends upon many factors which should be carefully considered by the intending purchasers. These factors are: (1) Source of water supply; (2) capacity of plant and period of operation; (3) the kind of pump; (4) the class of engine or driving power; (5) the first cost; (6) the fuel cost; (7) the cost of fixed charges and attendance. These factors are interdependent and should be considered together. Their relative importance will vary with local conditions and for that reason it is not possible to state definite rules which will apply in all cases. A study of the conditions affecting each factor is therefore necessary in each case.

SOURCE OF WATER SUPPLY

The source of water supply may be surface water supply, such as water occurring in rivers, lakes, canals (Pl. VII, Fig. A), etc., or may be ground water supply. Where surface water is available, the water will be developed by means of a proper intake, which for the simplest cases will consist of the suction pipe of the pump extending into the body of water. Where ground water is available the most common means of development is by wells.

Wells.—The well may be a dug, bored or drilled well. The most common form of well for individual pumping in California

is a drilled or bored well 10 to 16 inches in diameter or larger, lined with a casing which may be one of the three following types:

First.—Standard steel screw casing.

Second.—Single galvanized iron casing, No. 12 to 16 gauge, with joints riveted together.

Third.—Double black steel casing, No. 12 to 16 gauge, known as California stove-pipe casing, and very generally used in southern California. This casing is made of riveted steel sections 2 feet long placed with broken joints. The bottom of the casing consists of a starting section 15 to 20 feet long, made of triple thickness, riveted together, and with a steel shoe at the lower end.

The well and casing should extend into the water-bearing gravel sufficiently far to give a perforated area equal to at least five times the cross-section area of the well. The perforations are made with an improved cutting tool, and consist of six to eight slits made in each ring or circle, each slit 12 to 18 inches long and 3/8 to 3/4 inch wide. A space of 4 inches is skipped and another ring of slits staggered with the adjacent ones is made. Slits should not be over 18 inches long with stove-pipe casing.

In southern California, near Chino, the price of drilling deep wells is as follows:

For 10-, 12- and 14-inch wells in fine material, $1.25 per foot for first 500 feet.

For 16-inch wells in fine material, $1.50 per foot for first 500 feet.

For depths greater than 500 feet the price is 50 cents extra on each additional foot.

The cost per foot of steel stove-pipe casing is about as follows:

Diameter	12 Gauge	14 Gauge
10 in.	$1.12	$0.92
12	1.27	0.99
14	1.51	1.12
16	1.80	1.24

CAPACITY OF PLANT AND PERIOD OF OPERATION

The required capacity of the plant will depend on the area irrigated, the duty of water or depth of water required on the

land and the period of operation. For an average loam soil a total depth of 12 inches of water during the irrigation season will be sufficient for young orchards. For a full-bearing deciduous orchard 18 inches, and for a citrus orchard 24 inches, should be ample, while for alfalfa and other forage crops 24 to 36 inches is plenty. Where the cost of pumping is high, such as for small plants and high lifts, it will usually not be feasible to grow at a profit anything but orchards or other highly profitable crops. To reduce the cost of pumping, no excess water should be used, all losses should be prevented by careful irrigation and thorough cultivation, in which case a young orchard on fairly deep retentive soil may not require more than 6 to 9 inches of irrigation water and a full-bearing orchard not more than 12 to 15 inches for deciduous trees and 18 inches for citrus trees during the irrigation season. To put a depth of 2 feet of water on 1 acre, takes a flow of very nearly 1 cubic foot per second for 24 hours; this is equivalent to 450 U. S. gallons per minute for 24 hours. This relation can be applied to any case to obtain the size of the pump. For example, to irrigate a 40-acre orchard 1 1/2 feet deep, in an irrigation season of 120 days, requires 60 acre-feet in 120 days or 1/2 of an acre-foot per day. This will be obtained by a pump giving 1/4 cubic foot per second, or 110 U. S. gallons per minute, when the pump is operated continuously 24 hours a day every day during the irrigation season of 4 months. For a 10-acre orchard the required capacity based on the same conditions would be one-quarter of the above, or 28 gallons per minute or 1/16 of a cubic foot per second.

The above two examples are based on a pump operating continuously at the rates given above. While continuous operation decreases the required size of the plant, it is usually preferable to select a plant of larger capacity and operate it only a part of the time. This is especially desirable for very small orchards, in which case continuous operation gives a stream too small to irrigate with. The other disadvantages of continuous operation are:

First.—Continuous operation requires continuous irrigation and constant attention to operate the pumping plant. For very small tracts a regulating reservoir may be used, but it must be of considerable capacity to be of any service, and it must be lined with concrete to prevent seepage losses of the water, which when

pumped is too valuable to lose. Usually it is preferable to purchase a larger plant and do without a reservoir, except possibly a small reservoir to hold the water pumped during the night.

Second.—Continuous operation gives a small stream which cannot be applied economically.

Third.—Continuous operation means that the water cannot be applied to the different parts of the tract within a short time, so that only a small part of the orchard or farm receives the water when most needed, and the remainder must be irrigated either too early or too late.

Fourth.—A small plant is less efficient and requires a proportionately larger fuel consumption than a larger plant to pump the same quantity of water.

On the other hand, a very short period of operation requires a comparatively large pumping plant which will greatly increase the first cost of installation, the interest on the capital invested, the depreciation and fund necessary to provide for renewal. It also requires a larger source of supply, which may not always be available. For instance, the required flow may exceed the capacity of the well or may so lower the water plane that the cost of pumping will be increased. Also in many localities the power company may offer a low flat rate for continuous use.

Usually it is desirable to operate the pump not more than one-half to one-third of the time during the irrigation season, and often a shorter period is desirable. This requires a pumping plant two or three times or more the size required for continuous irrigation. The capacity of the pump must be sufficient in all cases to give a large enough stream to irrigate economically; even for the smallest orchards a stream of at least 5 to 10 miners' inches, or about 50 to 100 U. S. gallons per minute, is desirable.

For a full-bearing orchard 18 inches of irrigation water for deciduous trees and 24 inches for citrus trees, applied in three to four irrigations of 6 inches each, at intervals of 30 to 60 days, should be ample in most cases. As stated above, where the water has to be pumped to high elevation the higher cost of the water demands great care in its use, and 12 to 18 inches total depth of irrigation water would be sufficient.

The table below gives the required pump capacity for various sizes of orchards or farms and for different periods of operation. It is based on a depth of irrigation water of 6 inches each month.

The period of operation is given in number of 24-hour days that the pumping plant is operated each month. These days need not be consecutive; for instance if the operation period is 10 days, instead of applying 6 inches of water in one irrigation lasting 10 days the soil may be so porous and gravelly that it will not retain moisture, in which case it may be preferable to apply 3 inches at a time in two irrigation periods during the month, of 5 days each. The required pump capacity is given in U. S. gallons per minute.

NECESSARY CAPACITY OF PUMPS IN U. S. GALLONS PER MINUTE TO GIVE A 6-INCH DEPTH OF WATER ON THE LAND EACH MONTH WHEN OPERATED THE FOLLOWING NUMBER OF 24-HOUR DAYS EACH MONTH

Area, acres	30 days	20 days	15 days	10 days	5 days	2.5 days	1 day
5	19.	28.	38	56.	113	225	563
10	37.5	56.25	75	112.5	225	450	1 125
15	57.	85.	113	170.	340	675	1,690
20	75.	113.	150	225.	450	900	2,250
30	113.	169.	225	338.	675	1,350	3,375
40	150.	225.	300	450.	900	1,800	4,500
60	226.	338.	450	675.	1,350	2,700	6,750
80	300.	450.	600	900.	1,800	3,600	9,000
120	450.	675.	900	1,350.	2,700	5,400	13,500

The capacity of pumps for smaller or greater depths of water applied per month can be easily computed by proportion from the values given. For different areas and different periods of operation the capacity may be obtained by interpolation.

KINDS OF PUMPS

The kinds of pumps commonly used to raise water for irrigation are (1) centrifugal pumps, (2) power plunger pumps (3) deep well pumps, (4) air lift pumps, (5) hydraulic rams.

Where the source of water supply is a surface body of water, either a centrifugal pump, a power plunger pump or a hydraulic ram will be used; where the source of water supply is ground water developed by wells, usually either a centrifugal pump, a deep well pump or an air lift pump will be used, and in some cases a power plunger pump. For deep wells, usually the vertical centrifugal pump placed in a pit or an air lift pump is used. Hydraulic rams are used for small quantities of water such as for domestic purposes or for irrigation of small pieces of land.

They are economical in operation but require special conditions, such as a nearby stream or canal with sufficient fall in a short distance.

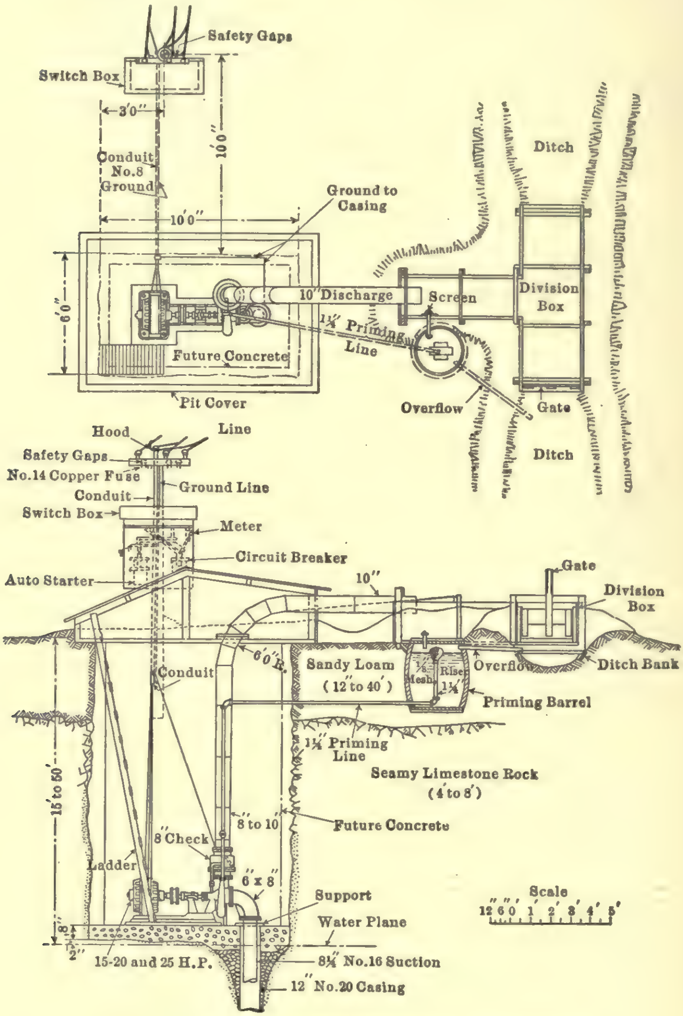


Fig. 70.—Details of horizontal pump installation.

A centrifugal pump consists of a circular casing with the inlet or suction end connected to the center and the outlet or discharge end formed tangent to the perimeter. Inside the casing is the

runner or impeller keyed on the shaft and revolving with it. It is formed of curved vanes closely fitting the casing. There are two general types: (1) the horizontal centrifugal pump, which has a horizontal shaft (Fig. 70); (2) the vertical centrifugal pump with a vertical shaft (Fig. 71). When in operation the impeller by revolving, imparts a velocity to the water between the vanes and forces it away from the center of the casing toward the perimeter or rim of the casing through the outlet and up the discharge pipe. This produces a partial vacuum at the center of the impeller which induces a flow through the suction pipe into the casing. The number of revolutions of the runner or speed of the pump has an exact relation to the head or lift against which the pump is working, and for every head there is a speed for which the pump works most efficiently. This speed can be obtained from the pump manufacturers. It is important that the pump be connected to an engine or motor which will give it the proper speed. Overspeeding is preferable to underspeeding, but either reduces the pump efficiency.

Simple centrifugal pumps specially designed and driven at a sufficiently high rate of speed may be used for lifts considerably over 100 feet, but usually the stock pump obtainable from the manufacturers is not suitable for lifts over 75 feet and for the smaller sizes the total lift should not exceed 50 feet. For higher lifts compound or multi-stage centrifugal pumps are used. These consist of two or more pumps connected in series; the discharge of the first pump or stage is delivered into the suction of the next pump and the operation is repeated, according to the number of stages. Usually 75 feet to 125 feet is allowed to each stage. When the required capacity of the pump is over 100 or 150 gallons per minute and the total lift less than 75 feet, the centrifugal pump is no doubt the best type of pump.

Centrifugal pumps are usually denoted by a number which represents the diameter of the discharge in inches. The efficient capacity of each size will vary to some extent with the speed of the pump, which depends on the total lift pumped against. The pumps can, therefore, not be rated accurately. The capacities given in the accompanying table are worked out from the ratings given by a reliable pump manufacturer, and are subject to considerable variations either above or below the values given.

Number of pump or diameter of discharge in inches	Capacity in U. S. gallons per minute	Capacity in second-feet, or acre-inches per hour	Number of acres irrigated 6 inches deep each month for operation period during month of						
			30 days	20 days	15 days	10 days	5 days	2 1/2 days	1 day
2	100	0.22	27	18	13	9	4 1/2	2 1/4	9/10
2 1/2	150	0.33	40	27	20	13	6 1/2	3 1/4	1 3/10
3	225	0.50	60	40	30	20	10	5	2
3 1/2	300	0.66	80	53	40	27	13	6 1/2	2 2/3
4	400	0.90	110	71	55	35	18	9	3 2/3
5	700	1.60	190	127	95	63	32	16	6 1/3
6	900	2.00	240	160	120	80	40	20	8
7	1,200	2.70	320	213	160	107	54	27	10 2/3
8	1,600	3.50	430	287	215	143	72	37	14 1/3

To start a centrifugal pump the suction pipe and the pump must be filled with water or primed. This may be done by closing the discharge pipe with a check valve and connecting the suction end of a hand pump to the top of the casing. Where a steam engine is used, a steam ejector may take the place of the hand pump. For small pumps and low lifts a foot valve on the end of the suction pipe may be used and the pump primed by pouring water in the casing or suction pipe. The disadvantage of a foot valve is that if the water is not clear a small stone or twig may lodge itself in the foot valve and prevent priming. This will necessitate that the suction pipe be uncoupled and the obstruction removed.

The pump must be placed as near as possible to the water-level to keep the suction lift down. While theoretically the suction lift may be as great as 33 feet at sea level and about 30 feet at an elevation of 3,000 feet, it is desirable not to exceed 20 feet and less is preferable. The horizontal centrifugal pump is preferable where the depth from the ground surface to the water plane is not large. But where the depth is large, it is necessary to place the pump in a deep pit, in which case either the vertical centrifugal pump or a deep well pump is generally used. A horizontal shaft centrifugal pump is usually more efficient than a vertical centrifugal, and it eliminates the end thrust of the shaft obtained with the vertical shaft which is difficult to balance properly. During the past few years a new type of vertical centrifugal, commonly named turbine centrifugal pump, has been developed for pumping from deep wells without the neces-

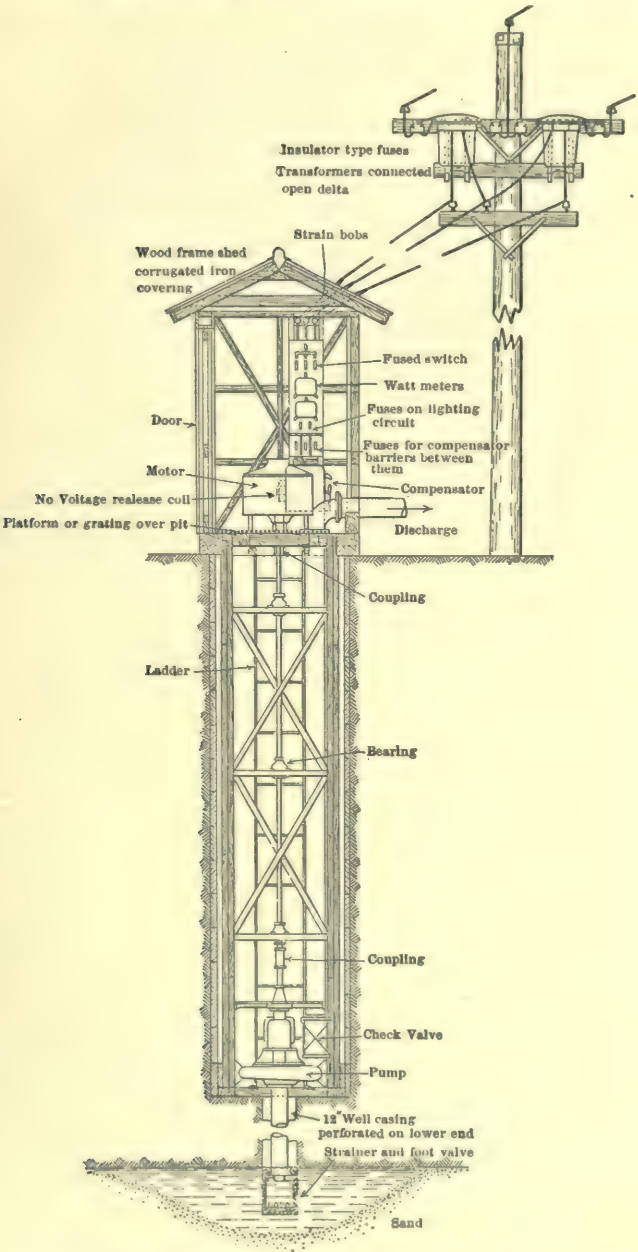


FIG. 71.—Details of vertical pump installation.

sity of a pit (Fig. 72, Plate VII, Fig. C). These pumps are installed inside the casing of bored wells 12 to 30 inches in diameter.

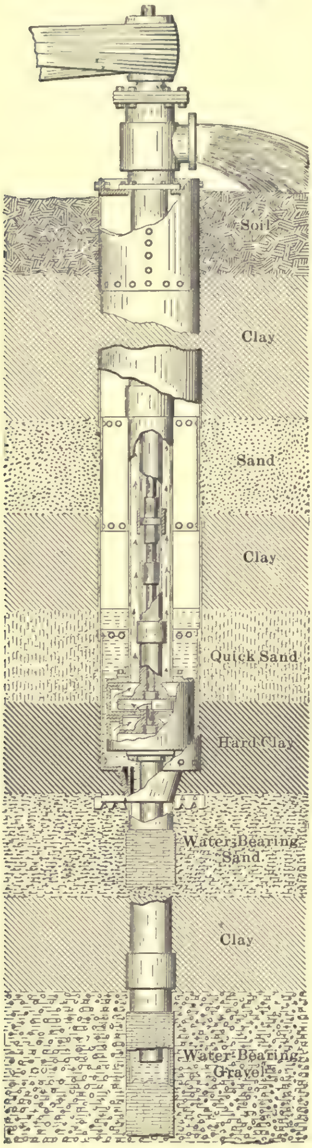


Fig. 72.—Deep well turbine centrifugal pump.

The plant efficiency can be increased by reducing the friction in the suction and discharge. As few bends as possible should be used and those should be made by using long turn elbows. The suction and discharge pipes should be larger than the intake and outlet openings of the pumps and joined to the pump with a reducer. The diameter of the suction pipe and especially of the discharge pipe should be 1 1/2 times the diameter of the intake, and if the discharge pipe is long it may be economy to make the diameter even larger. Where the source of water supply is a surface body of water, enlarging the lower end of the suction pipe will further decrease the friction. This may be done by a funnel-shaped section whose length is about 3 times the diameter of the suction pipe and whose large end is about 1 1/2 times the diameter of the pipe. The larger opening at the entrance to the suction pipe will decrease the tendency to suck up sand or gravel. When the water carries weeds, gravel, or other material a strainer should be used and the total area of the strainer should be at least twice the area of the suction pipe. The discharge pipe should not carry the water any higher than necessary.

Power piston or plunger pumps are used where the water is ob-

tained from a surface source or where the water is near the surface of the ground and the lift to the point of delivery is large. It consists of one or more cylinders, in each one of which a piston or plunger moving backward and forward sucks the water into the cylinder and forces it up the discharge pipe. When the cylinder has only one suction valve and one discharge valve, the motion of the piston in one direction causes suction and the displacement in the opposite direction forces the water through the discharge pipe. With two sets of valves so arranged that there is a discharge for each displacement of the piston, the pump is

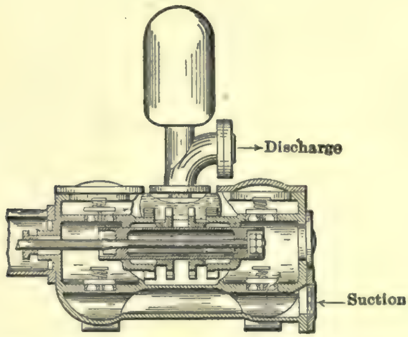


FIG. 73.—Double-acting cylinder of plunger pump.

known as a double-acting pump (Fig. 73). When the pump has two cylinders it is known as a duplex pump, with three cylinders it is a triplex pump, and in either case may be either double acting or single acting. The cylinders with the driving gears or pulleys are assembled and built at a height above the water plane which must not exceed the suction lift.

The capacity of the pump will depend on the diameter of the cylinder, the length of the stroke of the piston, and the number of strokes or revolutions per minute. The capacities of a few sizes of double-acting, single piston pumps, single-acting triplex pumps, and of double-acting duplex pumps are as follows:

Capacity of Double-acting, Single Piston Pump

Diameter of water cylinder, in	Length of stroke, in.	Revolutions or strokes per minute	U. S. gallons per minute
3	5	40	12.4
4	5	40	21.6
5	5	40	34.0
6	6	40	58.0
7	6	40	80.0
8	6	40	104.0

Capacity of Single-acting, Triplex Piston Pump

Diameter of water cylinder, in.	Length of stroke, in.	Revolutions or strokes per minute	U. S. gallons per minute
3	4	50	18
4	4	50	32
4	6	50	50
5	6	50	76
5	8	45	91
6	8	45	131
7	8	45	180
7	10	42	210
8	10	40	270
8	12	40	310
9	10	40	340

Capacity of Double-acting, Duplex Pumps

Diameter of water cylinder, in.	Length of stroke, in.	Revolutions or strokes per minute	U. S. gallons per minute
2 1/4	4	75	20
3	4	75	36
3 1/2	6	60	58
4	6	60	78
5	6	60	120
6	6	60	174
5	10	50	170
6	10	50	245
7	10	50	334
8	12	50	522
9	12	50	660

The sizes of pumps and the capacities vary with the different manufacturers. The values stated above show the approximate range of the different sizes. For small capacities the double-acting single piston pump may be used.

Deep well pumps are used where the water plane is at large depths below the ground surface. A deep well pump consists of a brass cylinder in which operate two plungers with valves (Fig. 74). The lower plunger is connected to a solid rod which fits into a hollow rod to which the upper piston is connected. The plungers are so operated by the driving power that the pump is double acting, one plunger moving up while the other moves down, so that there is a continuous discharge. Above the cylinder and connected to it is the vertical discharge or column pipe into which discharges the water passing through the valves in the plunger. The cylinder is about 2 inches smaller in diameter than the well casing and about 1 inch smaller than the delivery pipe; the cylinder and delivery pipe are both lowered into the well until the plungers are under water. At the surface the driving power and circular motion of the belt of the engine are transmitted to the driving rods by means of gears and levers combined into a power head designed to produce overlapping strokes so as to eliminate to some extent the pulsations, which are further decreased by an air chamber. The size ranges from 6-inch cylinders and 28-inch stroke to 16-inch cylinders and 36-inch stroke. The number of strokes ranges from sixteen to twenty-four per minute, depending on the lift and the size. The maximum lift is 350 feet. The capacity ranges from about 115 gallons per minute to a maximum of 1,000 gallons for the largest pump with extra long cylinder.

Air lift or compressed air pumping plants consist of: one or more air lift pumps, the air compressor with receiver and motive power, and the necessary piping to deliver the compressed air from the receiver to the pumps. Each pump (Plate VII, Fig. D) consists of: (1) the discharge pipe, which is smaller than the well casing and is placed inside of it, extending below the water surface to a depth equal to 1 1/2 or 2 times the lift measured from the water surface; (2) the air pipe, which is usually inside the discharge pipe but may, if the well is enough larger than the discharge pipe to so permit, be placed outside and connected at the lower end of the discharge pipe by means of standard fittings or special castings; (3) the foot piece, which is a special casting connected to the lower end of the air pipe and designed so as to admit the air evenly in small bubbles—there are various designs of patented foot pieces, but there is little differ-

ence in their efficiency; (4) in some cases the tail piece which forms a slightly enlarged extension of the lower end of the discharge pipe below the foot piece. The air is delivered through the foot piece at pressures varying according to the lift and the ratio of diameters between air pipe and water pipe, and its expansion

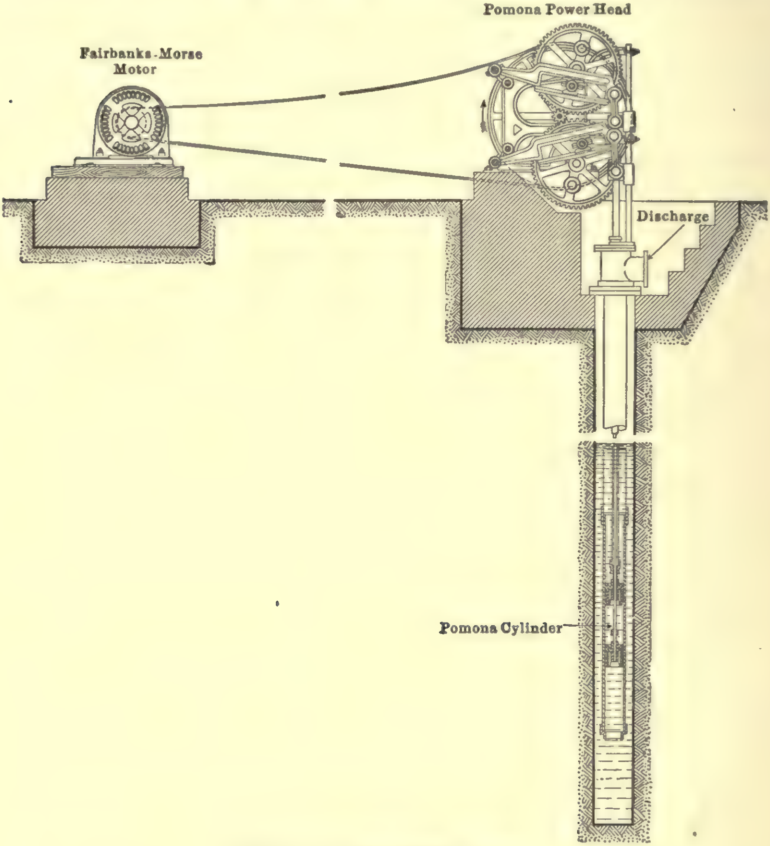


FIG. 74.—Deep well pump.

and displacement produce the lifting power. The relation between the volume of air supplied and the volume of water pumped for different lifts has been found by experiment to be as follows:

Head in feet..............	10	20	30	50	100
Ratio $\frac{\text{Cubic feet of air}}{\text{Cubic feet of water}}$	1.0	1.5	2.0	2.5	3.0

The velocity of water in the discharge pipe, based on the volume of water pumped, should not exceed 5 feet per second in order to keep down friction losses.

The compressor may be direct connected to a steam engine or gasoline engine or may be connected by means of belts, gears, etc., to the driving power which may be a steam engine, a gasoline engine or electric motor. The compressed air passes from the air cylinder to the receiver, which is used to store the air and equalize the pressure. From the receiver the air is conducted through pipes to each well.

The efficiency of the plant when properly installed, as calculated from the ratio of actual water horsepower to the indicated

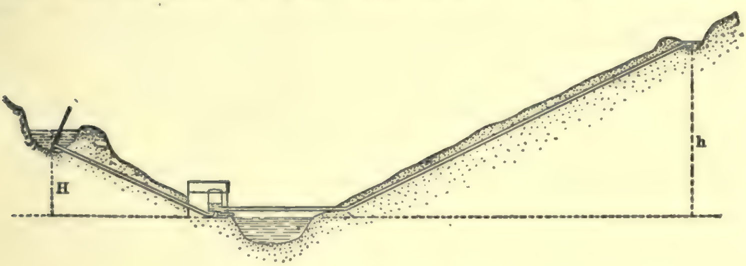


FIG. 75.—Hydraulic ram.

horsepower in the cylinder of the engine, is generally between 20 and 30 per cent. Air lifts are best adapted for pumping from several wells not farther apart than half a mile and where the wells are sufficiently deep to allow proper submergence.

The hydraulic ram works on the principle that a large volume of water falling through a low head will pump a smaller volume of water through a higher head. The ram consists of the valve box and air vessel, the supply or drive pipe which connects the valve box with the source of supply, and the delivery or discharge pipe which connects the air vessel with the point of delivery (Fig. 75). The efficiency of the plant is $E = qh/QH$, where q = volume of discharge water, h = discharge head in feet above ram, Q = volume of drive water, H = drive head in feet. For best results the ratio of the length of drive pipe to the length of drive head should not exceed 2.5, but it is practicable to increase this ratio to 25 and use a drive pipe 1,000 feet long. The delivery head may be anything up to about 250 feet and the

drive head anything above 18 inches. The efficiency diminishes as the ratio of delivery to drive head increases. With this ratio as great as 30 to 1 the efficiency will not be over 20 per cent.; with a ratio not greater than 4 to 1 the efficiency may be as high as 75 per cent.

Hydraulic rams are usually limited to small quantities of water. A notable example of a large plant for irrigation purposes is one installed at Sunnyside, Washington, for the irrigation of 240 acres of land. The plant was installed by the Columbia Steel Works of Portland, Oregon, and consists of eleven 6-inch rams, with a common discharge cylinder emptying into a 10-inch wood stave discharge pipe. The plant is used to irrigate 150 acres under 105 feet lift and 90 acres under 144 feet lift. The lifts are measured from rams. The drive head is 38 feet and the drive water 5 second-feet. The plant was furnished under guarantee to deliver 0.75 second-feet at higher outlet. The cost of plant is as follows:

11 6-inch rams and 3,212 feet of wrought-iron drive pipe . .	$3,200.00
1,900 feet of 10-inch wood discharge pipe	608.00
Installation complete	2,000.00
Total cost	$5,808.00

No maintenance except two visits per day to clear weeds out. An efficiency test gave the following results:

$$H = 37.6;\ h = 144.1;\ Q = 6.25;\ q = 1.15:$$

$$E = \frac{1.15 \times 144.1}{6.26 \times 37.6} = 0.70$$

ADAPTABILITY OF THE SEVERAL TYPES OF PUMPS FOR SMALL PUMPING PLANTS

Where the source of water supply is a stream or surface body of water, the choice is usually between a power pump and a centrifugal pump and will depend largely on the lift and capacity. Power pumps are best adapted to high heads above 75 feet and to small or moderate volumes of water, usually under 200 gallons per minute. For these conditions the efficiency of a power pump is usually greater than that of a centrifugal pump. For greater volumes the plunger pumps are comparatively expensive and centrifugal pumps are usually preferable unless the lift is exces-

sive. The centrifugal pump has the advantage that it is simple in construction, with no parts to get out of order, and that it is cheaper than a power pump.

Where the source of water supply is ground water with the water-table in the well at a depth below the surface not much greater or less than the limit of suction lift, so that a deep pit is not necessary, then the choice is between a centrifugal pump, a power pump and an air lift pump. The selection between the centrifugal and power pump will depend on a consideration of lift and capacity as explained above. Air lift plants have low efficiency, require a depth of well below the water-table equal to about twice the lift measured from the water-table, and are hardly to be considered in connection with separate small pumping plants. They are best adapted to a large number of wells (at least six or preferably more) placed close together. An air lift pump can be used advantageously for a well which is too crooked for the other types of pumps.

Where the source of water is ground water developed by deep wells with the water-table at a large depth below the surface (50 to 200 feet or more), the choice is between a vertical centrifugal pump in a pit, a turbine pump and a deep well pump which eliminates the pit. Deep well pumps are best adapted where the lift is in excess of 100 or 150 feet and for wells that do not yield more than about 400 gallons per minute. Their efficiency is higher than that of centrifugal pumps, but the cost of repairs and depreciation is greater.

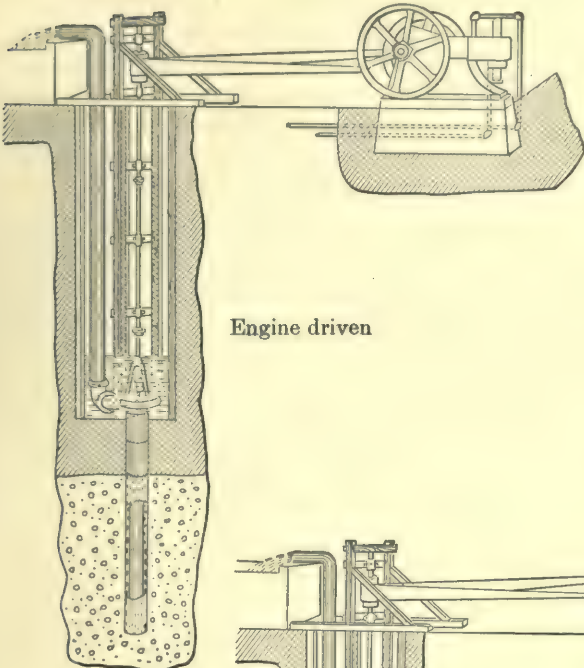
The selection should be made only after careful consideration of the first cost of the pump and the annual cost of fuel, operation and maintenance. Where the lift is high, the fuel cost will be considerable and it is good economy not to select the cheapest pump obtainable, but one that is guaranteed for its efficiency. On the other hand, if the pump is to be operated only during a very small portion of the season, it would be poor economy to invest a large capital in a high-grade pumping plant to save in fuel cost.

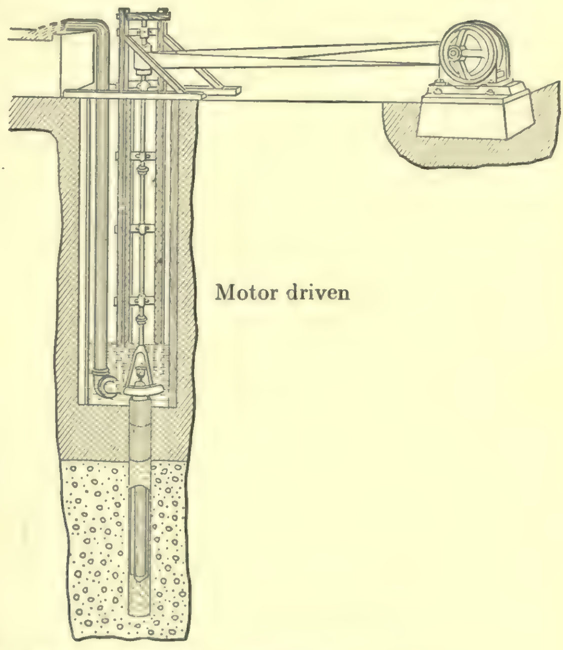
METHODS OF DRIVING

The driving power is generally either gasoline engine, steam engine, or electric motor. Centrifugal pumps are usually either direct connected (except for varying low heads) or connected by

means of belts, gears, or chains. Power pumps are connected by belts or gears. Direct connection is preferable when possible; it is more efficient and eliminates the adjustment of belt or chain necessary with the belt or chain driven pumps. The connection of these pumps and driving power must be such that the pumps will be given the speed or number of revolutions per minute for which they are designed and for which the highest efficiency is obtained. For this reason direct connection can only be used where the driving power and the pump have the same speed. The speed of centrifugal pumps is usually high; so is that of electric motors, and for this reason they can, if properly designed, be direct connected. This is done usually by means of a flexible coupling. Gasoline and steam engines are generally operated at a much lower speed than centrifugal pumps, and are therefore not direct connected unless the engine and pump are specially designed. This is done by some manufacturers. To obtain maximum efficiency with direct connection when the heads are low and subject to wide variation, it is necessary to change the runners of the pump to correspond to the different heads; some pumps are manufactured so that this can be done, but for these conditions it is easier to use belt connection and vary the sizes of the pulleys. Because power plunger pumps are operated at a low speed, they are not direct connected to the driving power. When connected by gears, belts, or chains, the driving gear and driven gear, or the driving pulley and driven pulley must be so proportioned that the pump will be given the correct speed. When a plunger pump is built with a steam engine in a single machine, with the piston or plunger of the water cylinder on the same driving rod as the piston of the steam cylinder, it is called a direct acting steam pump. The fuel consumption of a steam pump is greater than that of a steam driven power pump and so steam pumps are not considered.

Deep well pumps are usually equipped with gears and levers combined and connected with the driving rods of the pump, forming what is called the pump head, the object of which is to convert and transmit the circular motion of the driving power to the driving rods of the pump. The engine or motor is usually connected to the pump head by belts, but may be connected by means of gears. In some cases steam heads are provided in the place of the pump head.





FIGS. 76 and 77.—Belt-driven submerged pumps.

The power necessary to lift water is indicated in horsepower. A horsepower represents the energy required to lift 33,000 pounds 1 foot high in 1 minute; this is equivalent to 3,960 gallons of water per minute raised 1 foot high. This relation enables one to find the net horsepower required in any case by multiplying the discharge of the pump in gallons per minute by the total lift in feet and dividing by 3,960. The result obtained represents the useful water horsepower necessary to lift the water. The horsepower delivered by the engine to the belt or gears when the pump is belted or geared to the engine, or to the pump itself when direct connected is the brake horsepower, and must be greater than the useful water horsepower to allow for the loss of energy in the pump and transmission. The horsepower developed within the engine itself is the indicated horsepower, and must be greater than the brake horsepower to allow for the energy loss in the engine. Gasoline engines and motors are rated on brake horsepower, but gasoline engines are frequently overrated. Steam engines are rated on indicated horsepower.

The combined efficiency of a pumping plant represents the ratio of the useful water horsepower to the rated horsepower of the engine, and will vary considerably with the type of pump, method of connection of engine with pump, and the care taken in operating both pump and engine at the proper speed. In ordinary field practice a good pumping plant, properly installed, should easily reach the efficiency given in the following table:

EFFICIENCY OF CENTRIFUGAL PUMPING PLANTS AND BRAKE HORSEPOWER PER FOOT OF LIFT

Number of centrifugal pump	Discharge in U. S. gallons per minute	Water horsepower per foot of lift	Efficiency, per cent.	Brake horsepower per foot of lift
2	100	0.025	30	0.081
2 1/2	150	0.038	35	0.11
3	225	0.057	40	0.14
3 1/2	300	0.08	45	0.18
4	400	0.10	45	0.22
5	700	0.17	50	0.34
6	900	0.23	50	0.46
7	1.200	0.31	50	0.62
8	1.600	0.41	55	0.75

The efficiency of power plunger pumps varies with the size of the pump and with the lift. A greater efficiency is obtained with the higher lifts and with the larger sizes. The efficiencies of properly installed plunger pumps and the horsepower for various lifts are given in the following table:

EFFICIENCY OF POWER PLUNGER PUMPS.

Diameter of cylinder, inches	Length of stroke, inches	Capacity in U. S. gallons per minute		Efficiency and brake horsepower for lifts of				
				50 feet	100 feet	150 feet	200 feet	250 feet
3	4	18	Efficiency	0.30	0.40	0.42	0.45	0.45
			Horsepower	0.75	1.1	1.6	2.0	2.5
4	4	32	Efficiency	0.35	0.50	0.60	0.65	0.65
			Horsepower	1.2	1.5	2.0	2.5	3.1
4	6	50	Efficiency	0.35	0.50	0.60	0.65	0.65
			Horsepower	1.9	2.5	3.1	4.0	4.8
5	6	76	Efficiency	0.40	0.55	0.65	0.70	0.70
			Horsepower	2.4	3.5	4.4	5.5	6.7
5	8	90	Efficiency	0.40	0.55	0.65	0.70	0.72
			Horsepower	2.8	4.1	5.2	6.5	7.8
6	8	131	Efficiency	0.45	0.60	0.65	0.70	0.72
			Horsepower	3.6	5.5	7.5	9.3	11.4
7	8	180	Efficiency	0.45	0.60	0.65	0.70	0.72
			Horsepower	5.0	7.5	10.5	13.0	15.5
7	10	210	Efficiency	0.50	0.65	0.70	0.75	0.78
			Horsepower	5.25	8.0	11.0	14.0	17.0
8	10	270	Efficiency	0.50	0.65	0.70	0.75	0.78
			Horsepower	6.75	10.25	14.50	18.25	22.1
9	10	340	Efficiency	0.50	0.65	0.70	0.75	0.78
			Horsepower	8.5	13.0	18.0	23.0	28.0

The plant efficiency of deep well pumping plants as ordinarily installed and operated was found from measurements made on a number of pumping plants in southern California to be from 35 to 55 per cent. With proper installation and operation the plant efficiency or ratio between useful water horsepower and brake horsepower should be from 50 to 65 per cent.

The plant efficiency of air lift pumps expressed as the ratio between the useful water horsepower and the indicated horsepower in the engine cylinder was found from test on a number of such plants in southern California to average a little less than 20 per cent.

The above tables will give the size of the engine. The driving power may be either a gasoline engine, steam engine, or electric motor. A gasoline engine generally uses comparatively high-grade distillate, commonly called engine gasoline. During the past few years engines which have been developed to use cheaper low-grade distillates or crude oils have been put on the market, but they are still in the experimental stage for California asphalt oils. The main difficulty is the asphalt residuum which may occur upon the vaporization of the oil. It is reported, however, that satisfactory results have been obtained with a number of engines installed in California. The purchaser of an engine of this type should visit one or more engines of the same make which have been in actual operation for at least one season and find out from the owner what difficulties and troubles, if any, have developed in the operation. The main advantage of this type of engine is the very low fuel cost.

The methods of connecting the engine with the pump have been already considered. Other factors being equal, direct connection is preferable when possible. A few general considerations of the types of engines are given in the following paragraphs.

For small plants irrigating a few acres, the steam engine, although very reliable, is seldom used in California and need not be considered except where coal or wood is very cheap as compared to gasoline; this has been the case for some plants in Oregon, Washington, and New Mexico. However, for larger areas and where coal or oil is cheap, it may be more economical than either a gasoline engine or electric motor. For large plants operated continuously it may be economy to install an efficient boiler and a high-grade compound condensing, triple expansion, or quadruple expansion, steam engine, in order to decrease the fuel cost. For small plants, operated only for short periods during the irrigation season it is much more important to decrease the cost of installation. The interest on the capital invested and the depreciation of the plant are very important items of cost as compared to the fuel cost. For these reasons, unless the acreage is large and the lift very high, the steam plant should consist of a semi-portable locomotive type boiler and an ordinary slide valve steam engine.

A gasoline engine is fairly reliable if it is strongly built and operated with care. Cleanliness and proper attention are neces-

sary. All parts and bearings should be kept in fine adjustment and properly oiled, by examining the engine at least every 2 or 3 hours. The circulating water should be kept fairly hot, but not too hot. It should be nearly boiling as it comes out of the jacket. The engine should be regulated by means of a governor to give the proper speed to the pump. To keep down the fuel consumption the gasoline feed should be so adjusted that there will be a miss in every ten or twelve explosions, and the engine should be worked up to its full-rated capacity. Over 75 per cent. of the troubles in connection with gasoline engines are due to the sparking device. This can usually be remedied by cleaning all connections free from oil, scraping the ends of wires, tightening screws, replacing the batteries, and removing carbon from contact points.

Electric motors are reliable and easy to operate, requiring very little attention.

FIRST COST OF PLANT

The first cost of a pumping plant depends on the grade of machinery, the cost of transportation, the expense of installation. Because of these factors accurate estimates of cost cannot be given. However, the approximate cost values given below will be of value to the land owner who is considering the feasibility of a pumping plant. The values given represent the prices at the factory and do not include transportation and installation.

Approximate Cost of Single-stage Centrifugal Pumps

Number of pump	Capacity in gallons per minute	Cost
2	100	$42
2 1/2	150	51
3	225	57
3 1/2	300	65
4	400	75
5	700	85
6	900	115
7	1,200	145
8	1,600	170

The cost of two-step centrifugal pumps of the same size will be about 4 times the values given above.

APPROXIMATE COST OF TRIPLEX SINGLE-ACTING POWER PUMP

Diameter of water cylinder, inches	Length of stroke, inches	Capacity in gallons per minute	Height of lift, feet	Cost
4	8	65	75 to 100	$170
5	10	130	100	250
6	12	220	100	340
4	6	48	175	225
5	8	91	175	325
7	8	180	175	450
8	10	270	175	700
8	12	310	175	750

APPROXIMATE COST OF ELECTRIC MOTORS, GASOLINE ENGINES AND SIMPLE VALVE, NON-CONDENSING STEAM ENGINES, WITH LOCOMOTIVE BOILER AND AUXILIARIES

Horsepower	Cost of electric motors, 1,200 revolutions per minute	Cost of gasoline engines	Cost of steam engines
2	$70	....	....
3	85	....	....
5	110	$375	$500
10	200	550	625
15	230	700	800
20	320	850	925
25	360	1,000	1,000
30	....	1,200	1,200
40	450	1,600	1,350

The above costs are for pumps and engine, and do not include the accessories, the foundation, the labor of installation, and the housing. For an electric plant the cost of transformers should be added unless these are supplied by the electric company. The accessories will include the suction and discharge pipes, the valves and fittings, the primary pump, the connection between pump and engine. The suction pipe is usually made of steel; the discharge pipe may be steel or wood banded pipe and should cost delivered as shown in the following table.

For a rough estimate the total cost of valves, priming pump, all fittings and suction pipe, but not discharge pipe may be taken as about 10 per cent. of the cost of pump and engine for a gasoline or steam plant and 20 per cent. for an electric plant. The cost of installation should not exceed 5 per cent. The cost of a building to house the plant will range from about $25 for a small plant to $100 or more for a larger plant. The cost of transporta-

tion and hauling will depend on the railway charge and on the distance from the station to point of installation.

Cost of Pipes Safe for 150-foot Head

Diameter of pipe, inches	Cost per foot, wood banded pipe	Cost per foot, steel pipe
4	$0.15	$0.18
6	0.20	0.26
8	0.28	0.32
10	0.35	0.40
12	0.42	0.48
14	0.58	0.60
16	0.70	0.67
18	0.82	0.75
20	0.95	1.05

FUEL CONSUMPTION AND FUEL COST

The selection between a steam engine, gasoline engine and an electric motor will depend to some extent on the comparative cost of coal, gasoline and electrical energy.

A gasoline engine is usually guaranteed for a fuel consumption of one-eighth of a gallon per rated or brake horsepower per hour. A new engine well adjusted will come up to this efficiency, but an engine that has been operated some time will consume about 1/6 of a gallon of engine gasoline or distillate per brake horsepower per hour.

The fuel consumption of a steam engine will vary greatly with the type of boiler and engine. A small slide valve non-condensing engine under 25 horsepower will use probably 50 to 60 pounds of steam per brake horsepower per hour. A locomotive type of boiler should give 5 or 6 pounds of steam for 1 pound of coal or about 0.6 pounds of oil. Therefore, a small steam engine under 25 horsepower should consume about 10 pounds of coal per brake horsepower per hour or about 6 pounds of oil. Steam engines of the same type from 30 to 50 horsepower will consume from 8 to 5 pounds of coal per brake horsepower per hour or from 5 to 3 pounds of oil.

Electrical energy is measured in kilowatts. A kilowatt is equal to 1 1/3 horsepower, but because of the loss of energy in the motor 1 kilowatt will usually give about 1.1 brake horsepower. Based on this figure 1 brake horsepower hour is equal to 9/10 of a kilowatt hour.

The above values show that to produce 1 brake horsepower per hour requires either 1/6 of a gallon of distillate, about 10 pounds of coal, or 6 pounds of oil, or 9/10 of a kilowatt hour. Based on these figures the table below shows the cost of fuel per brake horsepower per hour for several equivalent cost values of fuel. In the table is also given the fuel cost of pumping 1 acre-foot of water through 1 foot of lift, assuming plant efficiency of 50 per cent. and 75 per cent.

COST OF FUEL PER BRAKE HORSEPOWER PER HOUR

Equivalent unit costs of fuel				Fuel costs (in cents)		
Cost of gasoline in cents per gallon	Cost of crude oil per barrel (335 pounds)	Cost of coal per ton	Cost of electric power per kilowatt hour in cents	Per brake horsepower per hour in cents	Per acre-foot of water lifted 1 foot high: 50 per cent. efficiency	Per acre-foot of water lifted 1 foot high: 75 per cent. efficiency
6	$0.55	$2.00	1.11	1.00	2.75	1.83
8	0.75	2.66	1.50	1.33	3.70	2.45
10	0.93	3.33	1.85	1.66	4.60	3.05
12	1.12	4.00	2.22	2.00	5.50	3.65
14	1.30	4.66	2.60	2.33	6.40	4.25
16	1.50	5.33	3.00	2.66	7.30	4.90
18	1.67	6.00	3.33	3.00	8.25	5.50
20	1.85	6.66	3.70	3.33	9.15	6.10
22	2.05	7.33	4.10	3.66	10.10	6.70
24	2.25	8.00	4.35	4.00	11.00	7.35
26	2.42	8.66	4.80	4.33	11.80	7.95

FIXED CHARGES AND ATTENDANCE

A. Fixed Charges.—The cost of installation represents a capital which if invested would bring in an income represented by the interest. It is therefore necessary to consider this interest as part of the cost of operation. To this should be added the annual cost of repairs, maintenance, and renewal. These items of cost represent the fixed charges. After 6 or 8 years a gasoline engine may need to have its cylinder rebored and a new piston provided, the cost of which is about one-tenth the cost of a new engine. With ordinary care the life of a gasoline engine may be taken as 10 years; the life of an electric motor about 15 to 20 years. The fixed charges on the entire plant may be taken as follows:

FIXED CHARGES

	Gasoline engine plant	Electric plant	Steam engine plant (small)
Depreciation and renewal	8 per cent.	5 per cent.	8 per cent.
Repairs and maintenance	3 per cent.	1 per cent.	2 per cent.
Interest	6 per cent.	6 per cent.	6 per cent.
	17 per cent.	12 per cent.	16 per cent.

B. Attendance.—An electric motor requires a minimum of attendance, small gasoline plants require frequent inspection, and steam engines require considerable attention and usually cannot be economically used for small plants operated during short periods. The cost of attendance for an electric motor pumping plant should not exceed 5 cents per hour, for a gasoline plant 10 cents per hour, and for a steam engine plant 30 cents per hour. While electric motors and gasoline engines are usually operated by the orchardist or irrigator, his time is valuable and a charge should be made for it.

FINAL SELECTION OF TYPE OF PLANT

The final selection of a pumping plant should be based on a careful consideration of the factors stated above. The best size of plant, the period of operation, the kind of engine or driving power, can only be correctly determined by a final consideration of the cost of installation and cost of operation. Where electric power is available, the choice is between a steam engine, a gasoline engine and an electric motor. The electric motor requires minimum attendance. It is reliable and its first cost is much less than that of a gasoline or steam engine. For these reasons if electric power is available, an electric motor is usually preferable and will often prove far more economical even should the cost of electrical energy be higher than the fuel cost for a gasoline or steam engine.

The application of the above information and cost data to any particular case is illustrated by the following examples:

A 20-acre orchard is to be irrigated by pumping from a surface body of water requiring no wells. The quantity to be applied is 6 inches per month, and the total depth in one season, 18 in. The lift is 50 feet and the discharge pipe 200 feet long. Engine gasoline or distillate costs 8 cents per gallon. Assuming the pump

is operated one-third of the time or ten 24-hour days each month, this will require a pump capacity of 225 gallons per minute, which is obtained with a No. 3 centrifugal pump and 7 horsepower engine, as shown in previous tables. The discharge pipe will be 4 inches in diameter. The first cost of plant and annual cost of operation will be about as follows:

First Cost of Plant

No. 3 centrifugal pump	$57.00
7 horsepower gasoline engine	450.00
Priming pump, suction pipe, fittings, etc	50.00
Freight charges and hauling	30.00
Wood-banded discharge pipe, 200 feet of 4 inches	40.00
Installation, 5 per cent. of cost	35.00
Building to house plant	40.00
Total cost	$702.00

Total Annual Cost of Operation

Fuel cost of 7 brake horsepower for 3 periods of 10 days each or 720 hours = $720 \times 7 \times 1.33 = 67{,}032$	$67.03
Fixed charges at 17 per cent. of first cost	120.00
Attendance 720 hours at 10 cents	72.00
Total cost for 20 acres	$259.03
Cost per acre, $12.95.	

Where electric power is obtainable, the first cost of plant and annual cost of operation for the same conditions, assuming the unit cost of electric power to be 3 cents per kilowatt hour, would be:

First cost of plant	$375.00
Total cost of operation (annual)	215.00
Cost of operation per acre	11.00

Tabulated below are the first costs of gasoline engine pumping plants and the costs of operation for orchards of 20, 40, and 80 acres for lifts of 50 feet and 150 feet, and for different periods of operation. For the higher lifts single-acting triplex pumps are used. The costs given are based on gasoline at 8 cents per gallon for a depth of irrigation of 18 inches for the lower lift and depths of 18 inches and 12 inches for the higher lift, it being assumed that by careful use of water, if the soil is retentive, 12 inches may be sufficient. The discharge pipe is assumed to be 200 feet long.

Cost of Pumping with Gasoline Engines and Centrifugal Pumps for 50-foot Lift

Engine Gasoline or Distillate, 8 Cents per Gallon

Area in acres	Number of 24-hour days pump is operated monthly	Capacity of pump, gallons per minute	Number of pump	Horsepower of engine	First cost of installation	Annual cost of operating per acre: 18-inch depth of water applied			
						Fuel	Fixed charges	Attendance	Total
20	5 1/2	400	4	12	$970	$3.20	$8.25	$1.90	$13.35
	10	225	3	7	700	3.40	6.00	3.60	13.00
	20	113	2	5	590	4.67	5.00	7.20	16.87
40	5	900	6	25	1,575	3.00	6.70	0.90	10.60
	11	400	4	12	970	3.20	4.10	2.00	9.30
	20	225	3	7	700	3.40	3.00	3.60	10.00
80	10	900	6	25	1,575	3.00	3.35	0.90	7.35
	22	400	4	12	970	3.20	2.05	2.00	7.25

Cost of Pumping with Gasoline Engines and Single-acting Triplex Pumps for 150-foot Lift

Area in acres	Number of 24-hour days pump is operated monthly	Capacity of pump, gallons per minute	Horsepower of engine	First cost of installation	Annual cost of operation per acre for a depth of irrigation water of:				
					18 inches				12 inches
					Fuel	Fixed charges	Attendance	Total	Total
20	8 1/3	270	15	$1,850	$6.60	$15.75	$3.00	$25.35	$22.15
	12 1/2	180	10	1,375	6.60	11.70	4.50	22.80	19.10
	25	90	6	1,025	7.27	8.70	9.00	24.97	19.54
40	13 1/4	340	18	2,200	5.80	9.35	2.40	17.55	14.81
	16 2/3	270	15	1,850	6.60	7.90	3.00	17.50	14.30
	25	180	10	1,375	6.60	5.85	4.50	16.95	13.25
80	26 1/2	340	18	2,200	5.80	4.70	2.40	13.90	10.16

The capacities of pumps, especially plunger pumps, and the sizes of engines vary with the different makes, and for that reason the exact sizes given may not be obtainable.

The above cost estimates are only approximate. They are based on the conditions stated above and are not applicable to all cases because of the varying conditions which make the installation of nearly every pumping plant a special problem. The estimates are made for gasoline engines and are considerably higher than for electric motors. The first example showed that with an electric plant the cost of pumping was only 83 per cent. of the cost with a gasoline plant. The tabulated values show the following interesting results:

First.—The cost per acre of pumping is much larger for a small area than for a large area.

Second.—The cost per acre does not vary considerably with the period of operation, and in some cases a plant moderately large operating for a shorter period will cost less per acre than a smaller plant operating a longer period. This is due to the lower fuel cost with the larger and more efficient plant and the decreased cost of attendance for the shorter period of operation, which overbalance the larger fixed charges. Even should the resulting cost be smaller for the smaller plant, the inconvenience due to pumping for a long period and the extra labor in irrigation may overbalance the saving in cost.

Third.—For the lifts assumed a period of operation equal to about ten 24-hour days during the month or one-third of the time during the irrigation season seems to be preferable with the centrifugal pump. With the higher price triplex plunger pumps a period of operation of one-third to two-thirds of the time is preferable.

COÖPERATIVE PUMPING

The lower cost per acre for larger areas shows the advantage to be gained by coöperation between small owners. By uniting and installing a large plant instead of several smaller plants, the cost of installation and operation is very much reduced, and the plant can be given more competent attention which relieves the orchardist and increases the life of the plant. Where by such coöperation several hundred acres can be brought together, a central steam plant to generate electric power, transmitted to the several electric motor pumping plants, is the most economical and best solution.

For separate plants above 20 or 40 horsepower, gas producer plants connected to gas engines may furnish the cheapest power where the proper fuel is obtainable. These plants are reliable and easily operated. They consist of the producer in which hard coal is placed and through a process of partial combustion, in the presence of air and steam, forms the gas which operates the engine. Gas producers operated on hard or anthracite coal have been in successful operation for a number of years, and those operating on soft bituminous coal and on oil are coming into use, but are still in the experimental stage. The fuel consumption

is very low, usually from 1 to 1 1/2 pounds of coal or 1/6 to 1/7 of a gallon of crude oil per horsepower hour; or 1/2 to 3/4 of a cent per horsepower hour with hard coal at $10 per ton and about 1/3 of a cent with oil at 2 cents per gallon. This is from two and a half to six times less than the fuel cost with gasoline at 12 cents a gallon. Producer gas plants are more expensive than gasoline engines and for smaller plants the fuel economy will be overbalanced by the larger interest and depreciation charges. For very large single plants, high duty steam engines may be the most economical form of installation.

LIMITS OF ECONOMICAL PUMPING

The cases previously worked out for gasoline engine pumping plants show that for small tracts of 20 to 80 acres the cost of lifting sufficient water to give a depth of irrigation water of 18 inches will range for a lift of 50 feet from about $8.85 per acre for the larger area to about $15 per acre for the smaller area, and for lifts of 150 feet the respective costs are about $15 and $25 per acre. These costs may seem high as compared with gravity water, but to obtain an idea of the economy and feasibility of developing water by pumping, comparisons must be made with the value of gravity irrigation water under the same conditions. Except in California, up to a few years ago gravity water obtainable without pumping has been available. For that reason pumping has not been necessary, and comparatively few pumping plants have been constructed. However, water is becoming more valuable, and the steps which many irrigation companies are taking to conserve water and prevent losses of transportation by carrying the water in concrete-lined canals and in pipes constructed at considerable expense show that in some localities, at least, water has become sufficiently valuable to justify pumping. If a comparison is made with water thus obtained, we find that the cost of construction of a well-constructed system may go up to $50 or $60 per acre and even higher. This cost is charged up to the land which is sold to the orchardist and in addition reasonable profit is made on the value of the land. It is probably conservative to assume that land under an irrigation system, in localities well developed and where irrigation is necessary, will cost at least $100 per acre more than similar land for which there

is no gravity supply. The chief advantage of gravity systems is the low annual cost of operation, usually less than $2 or $3 per acre, although in some cases it may be as much as $5 per acre or more; but if to this be added the interest on the difference in cost between land under the irrigation system and land which is to be supplied by pumping, assumed at $100, the total annual cost may be $10 to $15 per acre. This is about equal to the cost of pumping with gasoline engines to a height of 50 feet and about half as large as for lifts of 150 feet. Where electric power is available or for large pumping plants, the cost of pumping would compare very favorably with gravity water, even for higher lifts than those stated above.

Some of the advantages of underground pumped water as compared to water obtained from a gravity irrigation system are:

First.—An underground supply is more reliable and is not likely to be deficient before the end of the irrigation season.

Second.—The irrigator is independent and controls his own water supply, and is prepared to irrigate his crops at the best time.

Third.—The underground water is free from the seeds of weeds.

A consideration of pumping in some of the well-developed irrigated districts is of interest to show its feasibility. In eastern Washington water is being pumped in one case to an elevation of 250 feet above the source of supply. In the citrus district of southern California lifts above 200 feet are not unusual, and it is considered profitable to pump 460 feet. In the Pomona district of southern California the cost of pumped water averages $15 per acre for one acre-foot when purchased from irrigation companies, while for smaller private plants the cost is often greater. In 1905 the Irrigation Investigations Office of the United States Department of Agriculture made tests on various pumping plants, and these show that the cost of pumping at private plants of 10 to 100 horsepower, with lifts of 100 to 300 feet, varied from $10 to $90 per acre for 1 acre-foot of water.

There is a limit beyond which it is not economically feasible to pump. In California citrus districts lifts above 400 feet have been considered profitable. For favorable conditions, such as large plants and cheap fuel, this can perhaps be taken as the limit of profitable pumping when the crops grown are as highly profitable as citrus fruits, olives, apples, and other orchard products.

For alfalfa it will usually be profitable to pump as high as 100 feet for favorable pumping conditions and prices of alfalfa at \$10 to \$15 a ton in the stack. For lower prices for alfalfa and higher fuel cost, 40 feet may be the limit. In any case the limit of economical pumping can only be determined after a careful consideration of the many items of the cost of production and the price at which the products can be marketed.

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